Atmospheric Exposure Tests of Nailed Sheet-Metal Building Materials

United States Department of Commerce
National Bureau of Standards
Building Materials and Structures Report 128

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†Superseded by BMS116.

[List continued on cover page III]

UNITED STATES DEPARTMENT OF COMMERCE • Charles Sawyer, *Secretary*
NATIONAL BUREAU OF STANDARDS • A. V. Astin, *Acting Director*

Atmospheric Exposure Tests of Nailed Sheet-Metal Building Materials

Theodore H. Orem

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Foreword

The atmospheric exposure tests of the nailed sheet-metal building materials reported herein were initiated to determine the resistance of such materials to atmospheric corrosion and to point out how improper installation practices can cause serious corrosion.

While it is not yet possible to establish the relative resistance to corrosion of the different materials because of the short duration of the tests, the deleterious corrosion of some of the materials that has already taken place because of improper installation warrants reporting on this phase of the project at this time. Classification of the materials as to their relative merit to withstand exposure to the atmosphere will be considered after definite conclusions can be drawn.

It is anticipated that the results of the tests will be of value in making information available as to how to avoid undue maintenance costs that result from improper installation of the various building materials studied.

A. V. Astin, *Acting Director.*

Contents

Atmospheric Exposure Tests of Nailed Sheet Metal Building Materials

Theodore H. Orem

Tests of nailed metallic building sheets of aluminum, aluminum alloy, aluminum-coated steel, galvanized steel, and zinc alloy exposed for a period of 2 years to the atmospheres of Washington, D. C., and Hampton Roads, Va., are described. The tests indicate that improper installation practices can cause accelerated corrosion of such materials, but which when properly installed, may be expected to give long satisfactory service. Important conclusions and recommendations are given regarding the installation of sheet-metal building materials.

1. Introduction

Atmospheric corrosion tests of metals and alloys are a means by which the relative corrosion resistances of metallic materials in a given geographical location can be determined. Contrary to what would generally be expected, data from atmospheric exposure tests are seldom of value in estimating the life expectancies of metals and alloys under different conditions of exposure because factors that affect the corrosion of metallic materials in their end use are usually radically different from those that contribute to failures in the ordinary atmospheric exposure test. The latter tests generally are so designed that specimens of the material are isolated completely from all other metallic or nonmetallic materials that may accelerate their breakdown, thus making the atmosphere the only factor that can cause any change in the material.

If it were possible to use a metallic building material completely isolated from other materials that may have a corrosive effect on it, then data obtained from atmospheric tests could be used with reasonable accuracy in estimating the life expectancy of the particular material. However, the fact that some metallic materials used in building, particularly thin sheets used for roofing and siding, often fail in far less time than is indicated by the usual atmospheric exposure test data, suggests that factors other than the atmosphere contribute to the breakdown. This premature deterioration of the material usually is caused by contacts with dissimilar metallic materials of construction or by proximity to nonmetallic materials. These materials may be corrosive in themselves, or they may tend to produce conditions that will be corrosive to the metallic material.

In the building industry is often impractical, if not impossible, to avoid using materials that may accelerate the corrosion of one of the materials when they are brought into intimate contact. It is possible, however, to insulate the materials from each other by means of paints, mastics, waterproof papers, felts, etc., so that corrosion will be minimized.

Lack of knowledge of the potential seriousness of bringing metallic materials into direct contact with materials that may cause their corrosion, or economic considerations that prevent precautions against such contacts, often result in construction in which the metallic components will fail in a short time or require undue maintenance. However, the simple expedient of insulating dissimilar metallic contacts provides much longer life, with a minimum cost for upkeep.

The present study was conducted to determine the relative resistances to corrosion of the different sheet materials under conditions of proper building construction and to illustrate how improper construction can cause premature deterioration of metallic coverings for buildings.

2. Materials

The aluminum and zinc-base alloys used in this investigation are typical of materials available in 1947 for use in domestic building construction. The aluminum alloys (table 1) are identified by the suffix A and are of two general types, namely, (1) clad sheets (5A and 9A) having a thin cladding of aluminum or an aluminum alloy that is anodic to the core material and thus will retard its corrosion if it is exposed, and (2) unclad, or homogeneous, sheets, the entire cross sections of which are of the same composition. Characteristic microstructures of the aluminum and aluminum alloys used in this investigation are shown in figure 1.

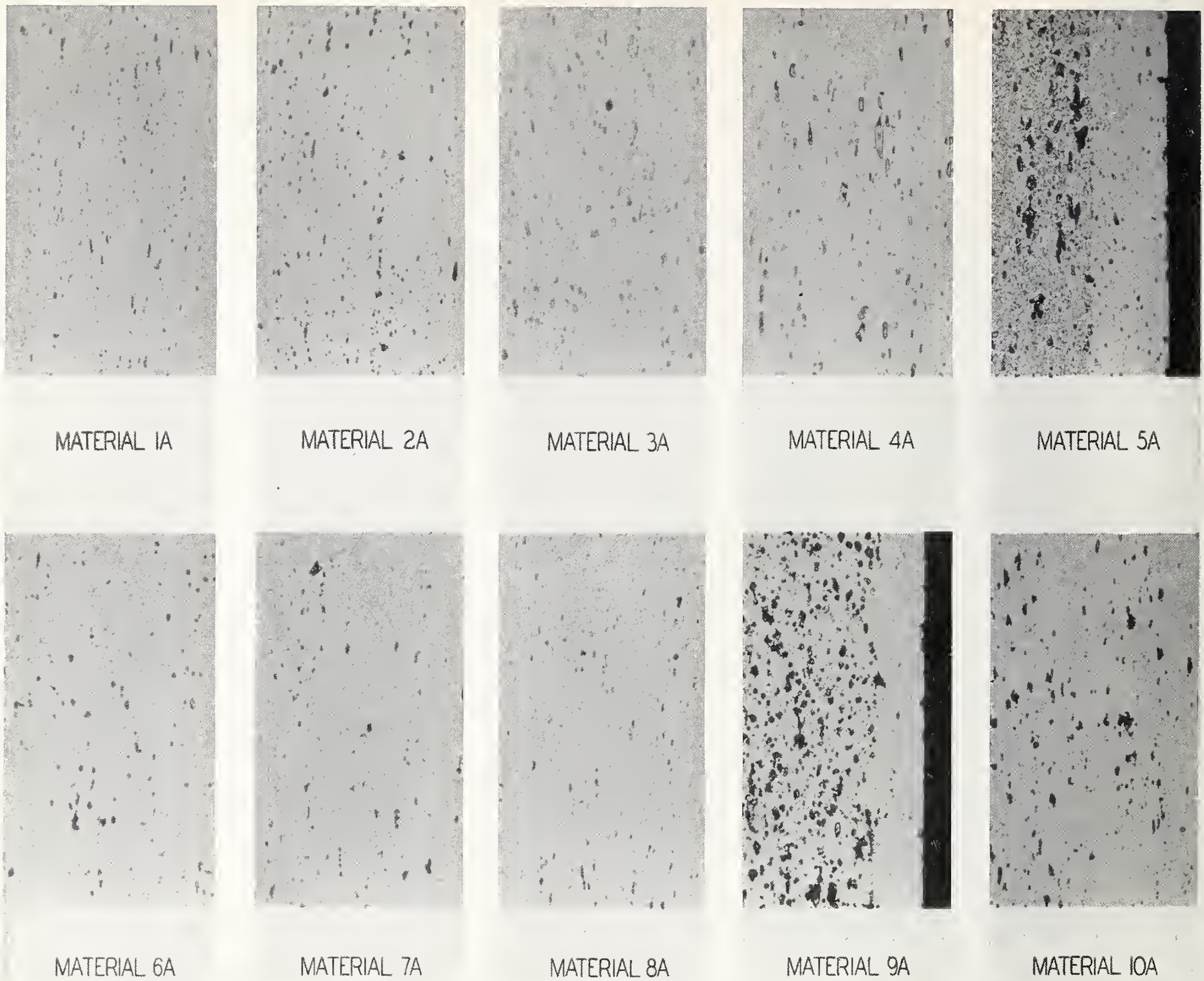

FIGURE 1. *Microstructure of aluminum base alloys.*

Materials 5A and 9A etched with Keller's etch; others unetched. Photomicrographs in rolling direction at ×250.

TABLE 1. *Nominal composition of materials investigated*

Specimen	Alloying elements							
	Cu	Mn	Mg	Zn	Cr	Fe	Al	Balance
	%	%	%	%	%	%	%	%
1A							99 min.	(1)
2A							99 min.	(1)
3A		1.2						(1)
4A		1.2						(1)
5A cladding				1.0				(1)
5A core		1.2	1.0					(1)
6A			2.5		0.25			(1)
7A			2.5		.25			(1)
8A							99	(1)
9A cladding							99 min.	(1)
9A core [2]								
10A	0.3 max.					0.7 max.	96 min.	(1)
1Z	1.0		.01	(3)				
2Z	1.0			(3)				
3Z	.5			(3)				
4Z	.5			(3)				
5Z	.5		.004	(3)				
6Z	.5		.004	(3)				

[1] Balance consists of aluminum and normal impurities. [2] Analysis unknown. [3] Balance consists of zinc and normal impurities.

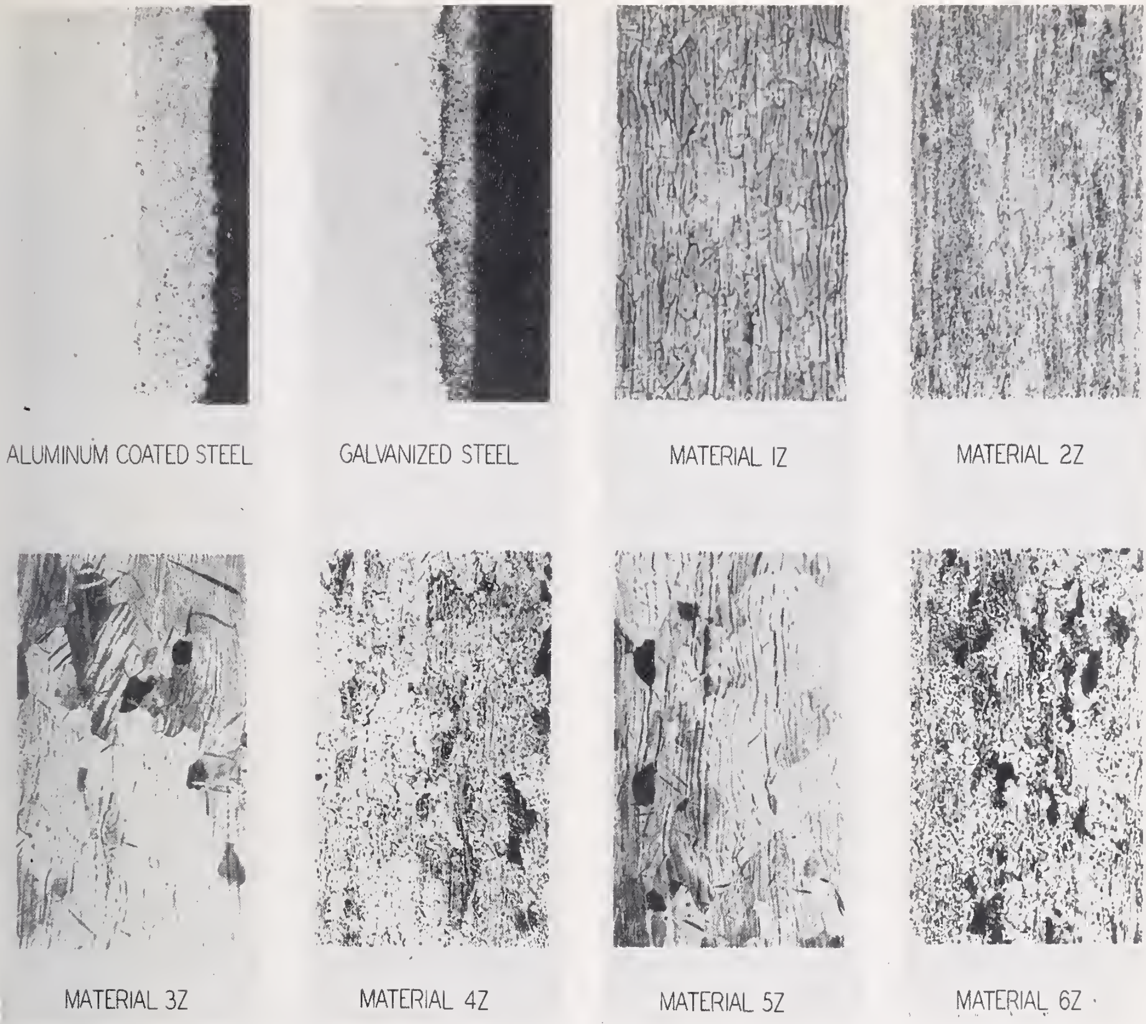

FIGURE 2. *Microstructures of aluminum-coated steel, galvanized steel and zinc base alloys.*

Zinc alloys etched with solution of chromic acid and sodium sulfate; aluminum-coated steel and galvanized steel unetched. Photographs in rolling direction at ×250.

The zinc alloys investigated are identified by the suffix Z and were of two general types. One contained copper as an alloying constituent, and the other contained copper and a small amount of magnesium (table 1). Two of the materials, one of each general type, 4Z and 6Z, were in the hot-rolled condition, and four materials, 1Z, 2Z, 3Z, and 5Z, two of each general type, were cold-rolled.

Spectrographic analysis of the alloys showed the presence of magnesium in all the alloys, although 2Z, 3Z, and 4Z were supposed to contain no magnesium. However, 2Z had magnesium in excess of that in the alloys in which magnesium was an added element, whereas 3Z and 4Z showed only faint traces of this element.

In addition to the aluminum and zinc-base alloy sheets, an aluminum-coated steel sheet having an aluminum coating between 0.0015 and 0.002 in. in thickness and a galvanized steel sheet (2 oz/ft^2) were investigated. Photomicrographs of these two materials and the zinc-alloy sheets are shown in figure 2.

3. Description

To simulate conditions in actual building construction, the different sheet materials were nailed to wood boards with different types of nails that might be used for this purpose. Each material was nailed to the boards (1) without any sealing washer, (2) with neoprene sealing washers, and (3) with lead sealing washers between the nail head and the sheet. The neoprene washers used were of two different types, one, a greyish-white molded washer commonly used for building purposes, and the other cut from neoprene sheet impregnated with carbon black.

The recommended practice for securing aluminum-alloy building sheets to wood sheathing or framing is to insulate the sheets from direct contact with the wood by means of water-resistant building paper, asphalt-impregnated felt, or paint, in order to preclude the possibility of corrosion due to the wood. In this investigation the specimens were purposely nailed directly to the wood in order to determine the possible seriousness of such a procedure.

Nails of bare steel, resin-coated steel, copper, aluminum alloy, galvanized steel, and cadmium-plated steel were used to fasten the sheets to the wood. As the latter two types generally are considered to be suitable substitutes for aluminum nails for fastening aluminum sheets, it was desirable to obtain data regarding the length of time such nails could be expected to give satisfactory service under different atmospheric conditions. Bare steel and resin-coated steel nails were used because these two types, particularly the former, are known to be unsatisfactory for this purpose, and it was desirable to emphasize this fact. The resin-coated steel nails also were used to determine if the film of resin would serve as an insulating material in preventing direct contact between the nail and the aluminum. Copper nails were used to illustrate the fact that two materials, such as aluminum and copper, each highly corrosion-resistant, can cause deleterious corrosion of the metal having the highest electronegative potential (the aluminum) when the two are brought into direct contact in the presence of moisture.

The aluminum-alloy specimens, except 1A and 10A, were attached to the boards with the galvanized nails by two methods. In one complete set of specimens the nailing was done through drilled holes, whereas in the other set, nailing was by the conventional method of driving directly through the sheet. This was done to determine whether driving the nail through the sheet removed enough of the galvanized coating to impair the corrosion resistance of the nail. In the case of materials 1A and 10A the galvanized nails were punched through the sheet in the upper left-hand and lower right-hand corners and were nailed through drilled holes in the center of the sheet. The specimens of galvanized steel and aluminum-coated steel were fastened to the boards with nail and washer combinations similar to those used on the aluminum specimens. These two materials were nailed through holes drilled in the sheets.

The specimens of zinc-alloy building sheets were nailed with bare steel and galvanized steel nails only. Insufficient space on the exposure racks prevented the use of all the different types of nails used with the aluminum specimens. As the zinc-alloy and the aluminum specimens were exposed at different times, a second set of galvanized steel sheets was exposed with the zinc-alloy sheets for comparison purposes.

The specimens for exposure tests were mounted on boards of basswood and yellow pine. Table 2 shows the woods to which the different materials were nailed and also the different nail and washer combinations used with each material.

The exposure racks at the Naval Air Station, Hampton Roads, Va., shown in figure 3, situated directly over the water of Willoughby Bay, are approximately 10 ft above mean tide level and face in an east-southeast direction. Specimens placed in the rack are inclined 45° to the horizontal. Some spray may reach the specimens during periods of high winds.

The racks at the National Bureau of Standards, figure 4, face directly south, and specimens placed in them are inclined 45° to the horizontal. A smokestack of the Bureau Power Plant is located approximately 150 ft northeast of the exposure-rack area.

All specimens were inspected immediately after removal from the racks and again after cleaning. The aluminum, aluminum-alloy, and aluminum-coated steel specimens were cleaned with concentrated nitric acid. The galvanized-steel and zinc-alloy specimens were cleaned with a solution of acetic acid and ammonium chloride. Inspection of the specimens involved examination for general corrosion from the atmosphere, galvanic corrosion due to contact with nails of material different from that of the sheet, corrosion due to contact with lead washers, and corrosion on the undersurface of the specimens where they contact the wood. The latter three types of corrosion are referred to in the inspection reports, tables 3, 4, 5, and 6, as "galvanic corrosion", "lead-washer corrosion", and "undersurface corrosion", respectively. The conditions of the cut edges of the aluminum-coated and galvanized-steel specimens and of the nails and washers were also noted.

Figures 5 and 6 illustrate the degrees of corrosion from contact with lead washers and of undersurface corrosion, respectively, observed on the aluminum alloys, as indicated in tables 3 and 4.

Figure 7 illustrates the various degrees of undersurface corrosion observed on the aluminum-coated and galvanized-steel specimens. Corrosion of the aluminum alloys from contact with dissimilar metal nails used without washers, listed under the column "Galvanic Corrosion" on the inspection charts, may be compared with the pertinent degrees of corrosion caused by contact of the sheets with lead washers, as shown in figure 5.

MATERIAL	NUMBER OF SETS AT EACH EXPOSURE SITE NAILED TO BASSWOOD	NUMBER OF SETS AT EACH EXPOSURE SITE NAILED TO YELLOW PINE	ALUMINUM - NO	ALUMINUM - NEOPRENE	ALUMINUM - LEAD	BARE STEEL - NO	BARE STEEL - NEOPRENE	BARE STEEL - LEAD	RESIN COATED STEEL - NO	RESIN COATED STEEL - NEOPRENE	RESIN COATED STEEL - LEAD	DR[1] - GALVANIZED - NO	DR - GALVANIZED - NEOPRENE	DR - GALVANIZED - LEAD	PN[2] - GALVANIZED - NO	PN - GALVANIZED - NEOPRENE	PN - GALVANIZED - LEAD	COPPER - NO	COPPER - NEOPRENE	COPPER - LEAD	CADMIUM PLATED STEEL - NO	CADMIUM PLATED STEEL - NEOPRENE	CADMIUM PLATED STEEL - LEAD
ALUMINUM AND ITS ALLOYS																							
1A	0	5	●	●	●	●	●	●	●	●	●				●	●	●	●	●	●	●	●	●
2A	5	0	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
3A	5	0	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
4A	5	0	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
5A	5	0	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
6A	5	0	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
7A	5	0	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
8A	5	0	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
9A	5	0	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
9A[3]	0	2	●	●	●	●	●	●							●	●	●	●	●	●	●	●	●
10A	0	5	●	●	●	●	●	●	●	●	●				●	●	●	●	●	●	●	●	●
ZINC ALLOYS																							
1Z	0	5				●	●	●							●	●	●						
2Z	0	5				●	●	●							●	●	●						
3Z	0	5				●	●	●							●	●	●						
4Z	0	5				●	●	●							●	●	●						
5Z	0	5				●	●	●							●	●	●						
6Z	0	5				●	●	●							●	●	●						
COATED STEELS																							
ALUMINUM COATED	5	0	●	●	●	●	●	●	●	●	●	●	●	●				●	●	●	●	●	●
GALVANIZED[4]	0	5	●	●	●	●	●	●	●	●	●	●	●	●				●	●	●	●	●	●
GALVANIZED[5]	0	5				●	●	●							●	●	●						

NAIL AND SEALING WASHER COMBINATION FOR EACH SET

1 DR DENOTES THAT THE NAIL WAS DRIVEN INTO THE WOOD THROUGH A HOLE DRILLED IN THE SHEET.

2 PN DENOTES THAT THE NAIL WAS PUNCHED THROUGH THE SHEET AND INTO THE WOOD.

3 THESE SPECIMENS EXPOSED AT LATER DATE THAN OTHER MATERIAL 9A SPECIMENS AFTER OBSERVING THE DELETERIOUS EFFECT OF BASSWOOD ON THE UNDERSURFACE OF THE LATTER.

4 THESE SPECIMENS EXPOSED AT SAME TIME AS ALUMINUM AND ALUMINUM ALLOY SPECIMENS.

5 THESE SPECIMENS EXPOSED AT SAME TIME AS ZINC ALLOY SPECIMENS.

TABLE 2. *Sheet-nail-washer combinations for atmospheric exposure tests of nailed sheet-metal building materials.*

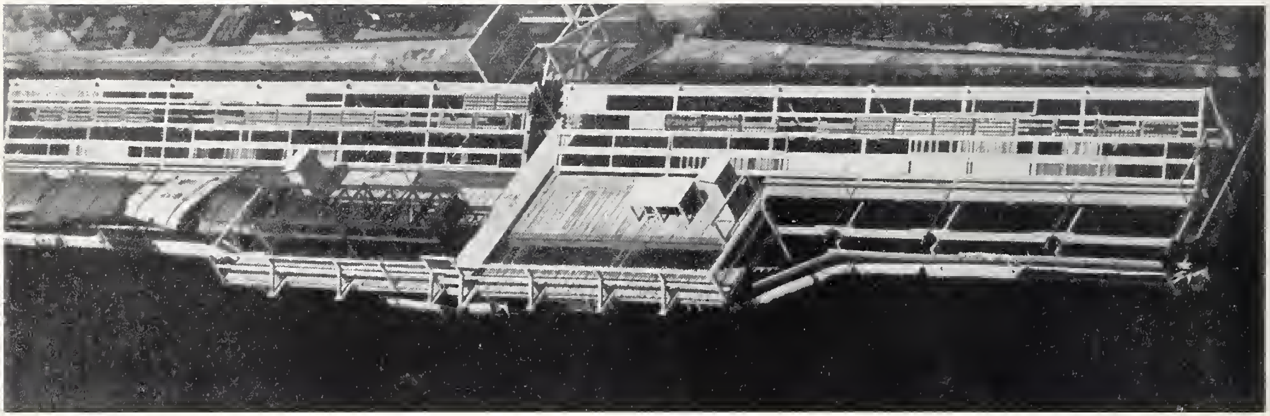

FIGURE 3. *Aerial view of atmospheric exposure test racks at Hampton Roads, Va. (Norfolk).*

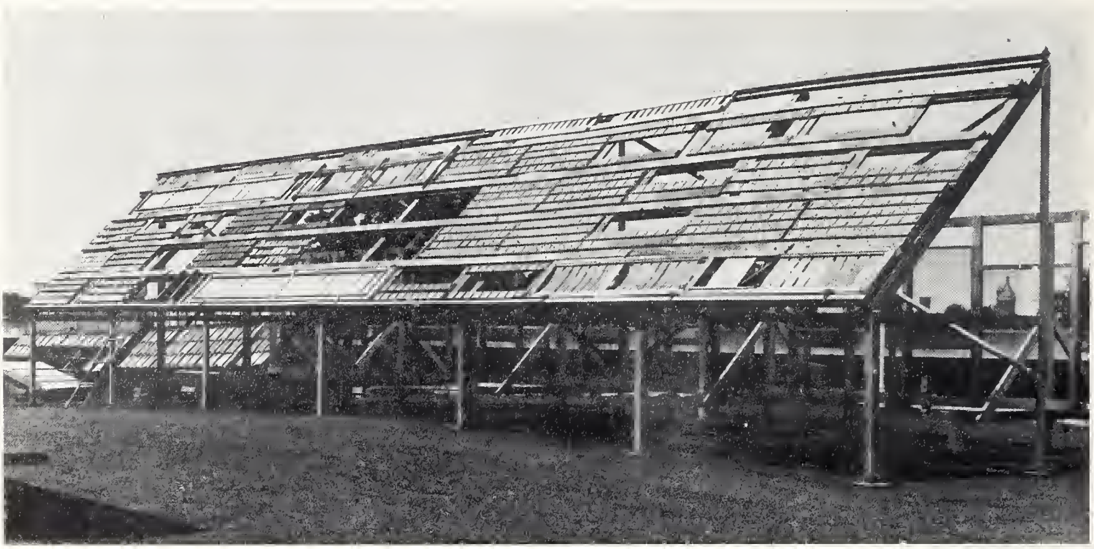

FIGURE 4. *Atmospheric exposure test racks on the roof of the Northwest Building at the National Bureau of Standards, Washington, D. C.*

○ SPECIMENS EXPOSED AT NATIONAL BUREAU OF STANDARDS
● SPECIMENS EXPOSED AT HAMPTON ROADS, VA. (NORFOLK)
"P" INDICATES PERFORATION

MATERIAL AND NAIL	CONDITION OF SHEET						GALVANIC CORROSION				CORROSION AROUND NEOPRENE WASHER				CORROSION BENEATH LEAD WASHER				UNDERSURFACE CORROSION				REMARKS
	*	SPOTTED		CORRODED																			
	DISC	SLIGHT	MOD	SLIGHT	MOD	SEVERE	NONE	SLIGHT	MOD	SEVERE	NONE	SLIGHT	MODERATE	SEVERE	NONE	SLIGHT	MODERATE	SEVERE	NONE	SLIGHT	MODERATE	SEVERE	
MATERIAL 6A																							
ALUMINUM	○ ●	○	●				○ ●				○ ●				○	●			○ ●				LITTLE CHANGE IN CONDITION OF
BARE STEEL	○ ●	○	●				○	●			○ ●				○		●			○ ●			SPECIMENS OVER THAT OF THOSE
RESIN STEEL	○ ●	○	●				○	●			○ ●				○		●			○ ●			EXPOSED FOR 3 MONTHS EXCEPT
GAL - DRILLED	○ ●	○	●				○ ●				○ ●				○	●			○ ●				FOR INCREASED SPOTTING OF SHEET.
GAL - PUNCHED	○ ●	○	●				○ ●				○ ●				○	●			○ ●				
COPPER	○ ●	○	●					○ ●			○ ●				○	●				●	○		
CADMIUM PLATE	○ ●	○	●				○ ●				○ ●				○	●				○ ●			
MATERIAL 9A																							
ALUMINUM	○ ●		●				○ ●				○ ●				○		●		○	●			SEVERITY OF CORROSION CAUSED BY
BARE STEEL	○ ●		●					○	●		○ ●				○			●		○	●		CONTACT OF SHEET WITH COPPER
RESIN STEEL	○ ●		●				○		●		○ ●				○		●			○	●		AND STEEL NAILS AND BY CONTACT
GAL - DRILLED	○ ●		●				○ ●				○ ●				○	●			○ ●				WITH LEAD WASHERS BECOMING
GAL - PUNCHED	○ ●		●				○ ●				○ ●				○	●			○ ●				APPARENT IN NORFOLK SPECIMENS.
COPPER	○ ●		●					○		●	○ ●				○			P			○	●	
CADMIUM PLATE	○ ●		●				○ ●				○ ●				○		●		○		●		
MATERIAL 3A																							
ALUMINUM	○ ●	●					○ ●				○ ●				○	●				○ ●			PERFORATION OF SHEET IN CASE OF
BARE STEEL	○ ●	●					○			P	○ ●				○		●			○		P	UNDERSURFACE CORROSION IS REMOTE
RESIN STEEL	○ ●	●					○	●			○ ●				○			P		○		P	FROM CONTACTS WITH WASHERS OR
GAL - DRILLED	○ ●	●					○ ●				○ ●				○	●			○ ●				NAILS.
GAL - PUNCHED	○ ●	●					○ ●				○ ●				○	●			○ ●				
COPPER	○ ●	●						○ ●			○ ●				○		●				○ ●		
CADMIUM PLATE	○ ●	●					○ ●				○ ●				○		●			○ ●			
MATERIAL 5A																							
ALUMINUM	○ ●		●				○ ●				○ ●				○	●				○ ●			CORROSION ON THIS MATERIAL IS A
BARE STEEL	○ ●		●				○	●			○ ●				○	●				○	●		NON-PITTING TYPE. UNDERSURFACE
RESIN STEEL	○ ●		●				○	●			○ ●				○	●				○	●		CORROSION IS SPOTTY AND OF REL-
GAL - DRILLED	○ ●		●				○ ●				○ ●				○	●			○	●			ATIVELY NON-UNIFORM DEPTH.
GAL - PUNCHED	○ ●		●				○ ●				○ ●				○	●			○ ●				THE PITTING PENETRATES THE CLAD
COPPER	○ ●		●					○ ●			○ ●				○	●					○ ●		SURFACE ONLY
CADMIUM PLATE	○ ●		●				○ ●				○ ●				○	●				○	●		
MATERIAL 1A																							
ALUMINUM	○ ●		●				○ ●				○ ●				○	●			○ ●				THE MATERIAL 1A AND MATERIAL 10A
BARE STEEL	○ ●		●				○ ●				○ ●				○	●			○ ●				SPECIMENS CONTINUE TO SHOW THE
RESIN STEEL	○ ●		●				○ ●				○ ●				○	●			○ ●				GOOD RESISTANCE TO CORROSION
GALVANIZED	○ ●		●				○ ●				○ ●				○	●			○ ●				SHOWN AFTER 3 MONTHS EXPOSURE
COPPER	○ ●		●					○ ●			○ ●				○	●			○ ●				AT BOTH SITES.
CADMIUM PLATE	○ ●		●				○ ●				○ ●				○	●			○ ●				
MATERIAL 10A																							
ALUMINUM	○ ●		●				○ ●				○ ●				○	●			○ ●				SEE REMARKS IMMEDIATELY
BARE STEEL	○ ●		●				○ ●				○ ●				○ ●				○ ●				ABOVE.
RESIN STEEL	○ ●		●				○ ●				○ ●				○ ●				○ ●				
GALVANIZED	○ ●		●				○ ●				○ ●				○ ●				○ ●				
COPPER	○ ●		●					○ ●			○ ●				○	●			○ ●				
CADMIUM PLATE	○ ●		●				○ ●				○ ●				○ ●				○ ●				
MATERIAL 7A																							
ALUMINUM	○ ●		●				○ ●				○ ●				○	●			○ ●				PERFORATION OF SHEET IN CASE OF
BARE STEEL	○ ●		●				○	●			○ ●				○	●				○	●		UNDERSURFACE CORROSION IS
RESIN STEEL	○ ●		●				○	●			○ ●				○	●				○		P	REMOTE FROM NAILS OR WASHERS
GAL - DRILLED	○ ●		●				○ ●				○ ●				○	●			○	●			ON SHEET WITH LEAD WASHER
GAL - PUNCHED	○ ●		●				○ ●				○ ●				○	●			○ ●				
COPPER	○ ●		●					○ ●			○ ●				○		●				○	●	
CADMIUM PLATE	○ ●		●				○ ●				○ ●				○	●			○	●			
MATERIAL 8A																							
ALUMINUM	○ ●		●				○ ●				○ ●				○	●				○ ●			SLIGHT INCREASE IN SPOTTING OF
BARE STEEL	○ ●		●				○	●			○ ●				○	●					○ ●		NORFOLK SPECIMENS AND INCREASE
RESIN STEEL	○ ●		●				○	●			○ ●				○	●					○ ●		IN UNDERSURFACE CORROSION. MAIN
GAL - DRILLED	○ ●		●				○ ●				○ ●				○	●				○ ●			DIFFERENCE IN THESE AND 3 MONTH
GAL - PUNCHED	○ ●		●				○ ●				○ ●				○	●				○ ●			SPECIMENS.
COPPER	○ ●		●					○ ●			○ ●				○	●				○	●		
CADMIUM PLATE	○ ●		●				○ ●				○ ●				○	●				○ ●			
MATERIAL 2A																							
ALUMINUM	○ ●	○	●				○ ●				○ ●				○	●				○ ●			NBS SPECIMENS BECAME SLIGHTLY
BARE STEEL	○ ●	○	●				○	●			○ ●				○	●				●	○		SPOTTED IN INTERVAL BETWEEN
RESIN STEEL	○ ●	○	●				○	●			○ ●				○	●				●	○		3RD AND 6TH MONTH.
GAL - DRILLED	○ ●	○	●				○ ●				○ ●				○	●				○ ●			
GAL - PUNCHED	○ ●	○	●				○ ●				○ ●				○	●				○ ●			
COPPER	○ ●	○	●					○ ●			○ ●				○	●					○ ●		
CADMIUM PLATE	○ ●	○	●				○ ●				○ ●				○	●				○ ●			
MATERIAL 4A																							
ALUMINUM	○ ●	●					○ ●				○ ●				○	●				○ ●			SLIGHT INCREASE IN UNDERSURFACE
BARE STEEL	○ ●	●					○	●			○ ●				○	●				○	●		CORROSION. MAIN DIFFERENCE IN
RESIN STEEL	○ ●	●					○	●			○ ●				○	●				○	●		THESE AND 3 MONTH SPECIMENS.
GAL - DRILLED	○ ●	●					○ ●				○ ●				○	●				○ ●			
GAL - PUNCHED	○ ●	●					○ ●				○ ●				○	●				○ ●			
COPPER	○ ●	●						○ ●			○ ●				○	●					○ ●		
CADMIUM PLATE	○ ●	●					○ ●				○ ●				○	●				○ ●	○		

* DISCOLORED

TABLE 3. *Aluminum alloy sheet-nail-washer inspection after 6 months of exposure.*

978996—52——2

○ SPECIMENS EXPOSED AT NATIONAL BUREAU OF STANDARDS
● SPECIMENS EXPOSED AT HAMPTON ROADS, VA. (NORFOLK)
"P" INDICATES PERFORATION

MATERIAL AND NAIL	CONDITION OF SHEET						GALVANIC CORROSION				CORROSION AROUND NEOPRENE WASHER				CORROSION BENEATH LEAD WASHER				UNDERSURFACE CORROSION				REMARKS
		SPOTTED		CORRODED																			
	DISC*	SLIGHT	MOD	SLIGHT	MOD	SEVERE	NONE	SLIGHT	MOD	SEVERE	NONE	SLIGHT	MODERATE	SEVERE	NONE	SLIGHT	MODERATE	SEVERE	NONE	SLIGHT	MODERATE	SEVERE	
MATERIAL 6A																							
ALUMINUM	○ ●	○	●	●			○ ●				○ ●					○	●			○ ●			SLIGHT INCREASE IN SPOTTING AND
BARE STEEL	○ ●	○	●	●				○ ●				○ ●				○	●			○	●		UNDERSURFACE CORROSION ONLY
RESIN STEEL	○ ●	○	●	●				○ ●				○ ●				○	●			○	●		DIFFERENCE BETWEEN THESE AND
GAL - DRILLED	○ ●	○	●	●			○ ●				○ ●					○ ●				○ ●			12 MONTH SPECIMENS DIFFERENCE
GAL - PUNCHED	○ ●	○	●	●			○ ●				○ ●				○	●				○ ●			IS VERY SLIGHT ON NBS SPECIMENS
COPPER	○ ●	○	●	●				○	●			○ ●				○	●				○ ●		
CADMIUM PLATE	○ ●	○	●	●			○ ●				○ ●				○		●			○	●		
MATERIAL 9A																							
ALUMINUM	○ ●		○ ●		●		○ ●				○ ●					○		P		○	●		NORFOLK SPECIMENS SHOW MARKED
BARE STEEL	○ ●		○ ●		●				○	●		○ ●				○		P			○	P	INCREASE IN CORROSION OVER THAT
RESIN STEEL	○ ●		○ ●		●			○		●		○ ●				○		P			○	P	AFTER 12 MONTHS EXPOSURE,
GAL - DRILLED	○ ●		○ ●		●		○ ●				○ ●					○ ●				○	●		WHERE CORROSION IS DUE TO CON-
GAL - PUNCHED	○ ●		○ ●		●		○ ●				○ ●				○	●				○		●	TACT WITH LEAD WASHERS AND
COPPER	○ ●		○ ●		●					○ ●		○		●		○		P				○ P	WOOD. NBS SPECIMENS LITTLE
CADMIUM PLATE	○ ●		○ ●		●		○ ●				○ ●					○		P		○		●	DIFFERENT FROM 12 MONTH ONES.
MATERIAL 3A																							
ALUMINUM	○ ●	○ ●		●			○ ●				○ ●				○	●					○	P	NBS SPECIMENS SHOW LESS UNDER-
BARE STEEL	○ ●	○ ●		●				○	●			○ ●			○		●			○		P	SURFACE CORROSION THAN ALL
RESIN STEEL	○ ●	○ ●		●				○ ●				○ ●			○		●			○		P	OTHER MATERIALS, WITH THE EX-
GAL - DRILLED	○ ●	○ ●		●			○ ●				○ ●					○ ●				○		P	CEPTION OF MATERIALS 1A AND 10A;
GAL - PUNCHED	○ ●	○ ●		●			○ ●				○ ●				○	●				○		P	AT NORFOLK MOST BADLY CORRODED
COPPER	○ ●	○ ●		●				○	●			○ ●				○	●			○		P	ON UNDERSURFACE, WITH THE EX-
CADMIUM PLATE	○ ●	○ ●		●			○ ●				○ ●				○	●				○		P	CEPTION OF MATERIAL 9A.
MATERIAL 5A																							
ALUMINUM	○ ●	○	●	●			○ ●				○ ●					○	●			○ ●			FIRST EVIDENCE OF PITTING FROM
BARE STEEL	○ ●	○	●	●				○	●			○ ●			○		●			○ ●			CONTACT WITH LEAD WASHER AND
RESIN STEEL	○ ●	○	●	●				○	●			○ ●			○		●			○	●		COPPER AND STEEL NAIL ON NOR-
GAL - DRILLED	○ ●	○	●	●			○ ●				○ ●				○	●				○	●		FOLK SPECIMENS. NO PITTING ON
GAL - PUNCHED	○ ●	○	●	●			○ ●				○ ●				○	●				○	●		UNDERSURFACES. NO PITTING ON
COPPER	○ ●	○	●	●				○	●			○ ●				○	●			○	●		NBS SPECIMENS.
CADMIUM PLATE	○ ●	○	●	●			○ ●				○ ●				○		●			○ ●			
MATERIAL 1A																							
ALUMINUM	○ ●	○	●	●			○ ●				○ ●				○		●			○ ●			UNDERSURFACE CORROSION IS VERY
BARE STEEL	○ ●	○	●	●				○ ●				○ ●			○		●			○ ●			SLIGHT ON BOTH NORFOLK AND NBS
RESIN STEEL	○ ●	○	●	●				○ ●				○ ●			○		●			○ ●			SPECIMENS. HEAVY WHITE CORROSION
GALVANIZED	○ ●	○	●	●			○ ●				○ ●				○	●				○ ●			PRODUCTS BETWEEN LEAD WASHERS
COPPER	○ ●	○	●	●				○	●			○ ●				○	●			○ ●			AND SHEET ON NORFOLK SPECIMENS.
CADMIUM PLATE	○ ●	○	●	●			○ ●				○ ●				○	●				○ ●			
MATERIAL 10A																							
ALUMINUM	○ ●	○	●	●			○ ●				○ ●				○	●				○ ●			REMARKS IMMEDIATELY ABOVE APPLY
BARE STEEL	○ ●	○	●	●				○ ●				○ ●			○		●			○ ●			TO THESE SPECIMENS ALSO
RESIN STEEL	○ ●	○	●	●				○ ●				○ ●			○	●				○ ●			
GALVANIZED	○ ●	○	●	●			○ ●				○ ●				○	●				○ ●			
COPPER	○ ●	○	●	●				○ ●			○	○ ●				○	●			○ ●			
CADMIUM PLATE	○ ●	○	●	●			○ ●				○ ●				○	●				○ ●			
MATERIAL 7A																							
ALUMINUM	○ ●	○	●	●			○ ●				○ ●				○		●				○ ●		PRINCIPAL DIFFERENCE BETWEEN
BARE STEEL	○ ●	○	●	●				○ ●				○ ●				○	●				○ ●		THESE AND 12 MONTH SPECIMENS
RESIN STEEL	○ ●	○	●	●				○ ●				○ ●				○	●				○ ●		IS IN SLIGHTLY INCREASED UNDER-
GAL - DRILLED	○ ●	○	●	●			○ ●				○ ●				○	●				○	●		SURFACE CORROSION, SLIGHT
GAL - PUNCHED	○ ●	○	●	●			○ ●				○ ●				○		●			○ ●			INCREASES IN SPOTTING AT BOTH
COPPER	○ ●	○	●	●				○	●			○ ●				○	●			○	●		SITES.
CADMIUM PLATE	○ ●	○	●	●			○ ●				○ ●				○		●			●	○		
MATERIAL 8A																							
ALUMINUM	○ ●		○ ●	●			○ ●				○ ●				○	●				○ ●			THESE SPECIMENS NOT APPRECIABLY
BARE STEEL	○ ●		○ ●	●				○ ●				○ ●			○	●					○ ●		DIFFERENT THAN 12 MONTH SPECI-
RESIN STEEL	○ ●		○ ●	●				○ ●				○ ●			○	●					○ ●		MENS EXCEPT FOR INCREASED SPOT-
GAL - DRILLED	○ ●		○ ●	●			○ ●				○ ●				○	●				○ ●			TING. ONLY VERY SLIGHT INCREASE
GAL - PUNCHED	○ ●		○ ●	●			○ ●				○ ●				○	●				○ ●			IN UNDERSURFACE CORROSION.
COPPER	○ ●		○ ●	●				○ ●				○ ●				○	●			○	●		
CADMIUM PLATE	○ ●		○ ●	●			○ ●				○ ●				○	●				○ ●			
MATERIAL 2A																							
ALUMINUM	○ ●		○ ●	●			○ ●				○ ●				○	●				○	●		UNDERSURFACE CORROSION ON NBS
BARE STEEL	○ ●		○ ●	●				○ ●				○ ●			○		●			○	●		SPECIMENS LITTLE DIFFERENT THAN
RESIN STEEL	○ ●		○ ●	●				○ ●				○ ●			○		●			○	●		THAT AFTER 12 MONTHS; SLIGHT
GAL - DRILLED	○ ●		○ ●	●			○ ●				○ ●				○	●				○	●		INCREASES ON NORFOLK SPECIMENS,
GAL - PUNCHED	○ ●		○ ●	●			○ ●				○ ●				○	●				○	●		PARTICULARLY THOSE NAILED WITH
COPPER	○ ●		○ ●	●				○ ●				○ ●				○	●			○	●		STEEL AND GALVANIZED (PUNCHED)
CADMIUM PLATE	○ ●		○ ●	●			○ ●				○ ●				○	●				○ ●			NAILS.
MATERIAL 4A																							
ALUMINUM	○ ●	○ ●		●			○ ●				○ ●				○	●				○ ●			UNDERSURFACE CORROSION ON NOR-
BARE STEEL	○ ●	○ ●		●				○ ●				○ ●			○		●			○	●		FOLK SPECIMENS NAILED WITH GAL-
RESIN STEEL	○ ●	○ ●		●				○ ●				○ ●			○		●			○	●		VANIZED NAILS CONSIDERABLY
GAL - DRILLED	○ ●	○ ●		●			○ ●				○ ●					○ ●					○ ●		INCREASED OVER THAT AT 12 MOS.
GAL - PUNCHED	○ ●	○ ●		●			○ ●				○ ●				○	●					○ ●		THIS CORROSION ON SOME NBS
COPPER	○ ●	○ ●		●				○	●			○ ●				○	●				○ ●		SPECIMENS (STEEL AND CAD PLATED
CADMIUM PLATE	○ ●	○ ●		●			○ ●				○ ●					○ ●				○ ●			NAILS) LESS THAN AT 12 MONTHS.

* DISCOLORED

TABLE 4. *Aluminum alloy sheet-nail-washer inspection after 24 months of exposure.*

ALUMINIZED STEEL SHEET - NAIL - WASHER INSPECTION AFTER 6 MONTHS EXPOSURE

NAIL	CONDITION OF SHEET: CORRODED SLIGHT	CORRODED MOD	CORRODED SEVERE	RUSTED SLIGHT	RUSTED MOD	RUSTED SEVERE	GALVANIC CORROSION: NONE	SLIGHT	MODERATE	SEVERE	CORROSION AROUND NEOPRENE WASHER: NONE	SLIGHT	MODERATE	SEVERE	CORROSION BENEATH LEAD WASHER: NONE	SLIGHT	MODERATE	SEVERE	UNDERSURFACE CORROSION: NONE	SLIGHT	MODERATE	SEVERE	REMARKS
ALUMINUM	●						○ ●				○ ●				○		●			○	●		PRINCIPAL DIFFERENCE BETWEEN 3 AND 6 MONTH
BARE STEEL	●						○	●			○ ●				○		●			○	●		SPECIMENS IS IN THE AMOUNT OF UNDERSURFACE
RESIN STEEL	●						○	●			○ ●				○		●			○	●		CORROSION. SLIGHT INCREASE IN AMOUNT OF GEN-
GALVANIZED	●						○ ●				○ ●				○		●			○		●	ERAL CORROSION AND SLIGHT EVIDENCE OF RUST
COPPER	●							○	●		○	○ ●			○		●				○	●	THRU PIN POINT CORROSION ON NORFOLK SPECIMENS.
CADMIUM PLATED	●						○ ●				○ ●				○		●				○ ●		NO UNDERSURFACE CORROSION ON NBS SHEET NAILED
																							WITH CD PLATED NAIL-LEAD WASHER; SAME SEVERE AT 6

GALVANIZED STEEL SHEET - NAIL - WASHER INSPECTION AFTER 6 MONTHS EXPOSURE

NAIL	CONDITION OF SHEET: SPANGLES CLEAR	SPANGLES FAINT	SPANGLES INVISIBLE	RUSTED SLIGHT	RUSTED MOD	RUSTED SEVERE	GALVANIC CORROSION: NONE	SLIGHT	MOD	SEVERE	CORROSION AROUND NEOPRENE WASHER: NONE	SLIGHT	MODERATE	SEVERE	CORROSION BENEATH LEAD WASHER: NONE	SLIGHT	MODERATE	SEVERE	UNDERSURFACE CORROSION: NONE	SLIGHT	MODERATE	SEVERE	REMARKS
ALUMINUM	○ ●						○ ●				○ ●					○ ●			○	●			NO APPARENT INCREASE IN SURFACE CORROSION OVER
BARE STEEL	○ ●							○ ●			○ ●					○ ●			○	●			THAT ON 3 MONTH SPECIMENS. SLIGHTLY MORE LEAD
RESIN STEEL	○ ●							○ ●			○ ●					○ ●			○	●			WASHER CORROSION THAN ON NORFOLK 3 MONTH
GALVANIZED	○ ●						○ ●				○ ●					○ ●			●	○			SPECIMENS. LESSER UNDERSURFACE CORROSION ON NOR-
COPPER	○ ●							○ ●			○ ●					○ ●				○ ●			FOLK SPECIMENS NAILED WITH GALVANIZED, COPPER
CADMIUM PLATED	○ ●						○ ●				○ ●					○ ●				○ ●			AND CD PLATED NAILS IS VERY OBVIOUS COMPARED TO
																							3 MONTH SPECIMENS BUT WITH NO APPARENT REASON.

ZINC ALLOY SHEET - NAIL - WASHER INSPECTION AFTER 6 MONTHS EXPOSURE

NAIL AND MATERIAL	CONDITION OF SHEET: LUSTER SHINING	LUSTER GLIMMERING	LUSTER DULL	CORRODED SLIGHT	CORRODED MOD	CORRODED SEVERE	GALVANIC CORROSION: NONE	SLIGHT	MOD	SEVERE	CORROSION AROUND NEOPRENE WASHER: NONE	SLIGHT	MODERATE	SEVERE	CORROSION BENEATH LEAD WASHER: NONE	SLIGHT	MODERATE	SEVERE	UNDERSURFACE CORROSION: NONE	SLIGHT	MODERATE	SEVERE	REMARKS
GALVANIZED STEEL SHEET																							SPANGLES CLEARLY VISIBLE ON GALVANIZED
BARE STEEL				●				○ ●			○ ●					○ ●				○ ●			SHEET AFTER CLEANING. SURFACE, GALVANIC,
GALVANIZED				●			○ ●				○ ●					○ ●				○ ●			LEAD WASHER AND UNDERSURFACE COR-
MATERIAL 1Z																							ROSION IS VERY SLIGHT WHERE NOTED.
BARE STEEL			○ ●	○ ●				○ ●				○ ●				○ ●				○ ●			LITTLE CHANGE IN CORROSION OF ZINC
GALVANIZED			○ ●	○ ●			○ ●				○ ●					○ ●				○ ●			ALLOYS OVER THAT OBSERVED AT THE
MATERIAL 2Z																							END OF 3 MONTHS EXPOSURE EXCEPT FOR
BARE STEEL			○ ●	○ ●				○ ●				○ ●				○ ●				○ ●			AN INCREASED INTENSITY OF PITTING ON
GALVANIZED			○ ●	○ ●			○ ●				○ ●					○ ●				○ ●			MATERIALS 3Z AND 5Z EXPOSED AT NBS
MATERIAL 3Z																							SAME MATERIALS AT NORFOLK UNCHANGED.
BARE STEEL		○	●	○ ●				○ ●				○ ●				○ ●				○ ●			SLIGHT PITTING AROUND NEOPRENE WASH-
GALVANIZED		○	●	○ ●			○ ●				○ ●					○ ●				○ ●			ERS ON THE MATERIAL 3Z AND 5Z SHEETS
MATERIAL 4Z																							NAILED WITH GALVANIZED NAILS. THIS IS
BARE STEEL			○ ●	○ ●				○ ●				○ ●				○ ●				○ ●			PROBABLY DUE TO THE LODGING OF DIRT
GALVANIZED			○ ●	○ ●			○ ●				○ ●					○ ●				○ ●			AND DUST PARTICLES AROUND THE WASHER.
MATERIAL 5Z																							
BARE STEEL		○	●	○ ●				○ ●				○ ●				○ ●				○ ●			
GALVANIZED		○	●	○ ●			○ ●				○ ●					○ ●				○ ●			
MATERIAL 6Z																							
BARE STEEL			○ ●	○ ●				○ ●				○ ●				○ ●				○ ●			
GALVANIZED			○ ●	○ ●			○ ●				○ ●					○ ●				○ ●			

○ SPECIMENS EXPOSED AT NATIONAL BUREAU OF STANDARDS

● SPECIMENS EXPOSED AT HAMPTON ROADS, VA. (NORFOLK)

TABLE 5.

ALUMINUM COATED STEEL SHEET - NAIL - WASHER INSPECTION AFTER 24 MONTHS EXPOSURE

NAIL	CONDITION OF SHEET						GALVANIC CORROSION				CORROSION AROUND NEOPRENE WASHER				CORROSION BENEATH LEAD WASHER				UNDERSURFACE CORROSION				REMARKS
	CORRODED			RUSTED																			
	SLIGHT	MOD	SEVERE	SLIGHT	MOD	SEVERE	NONE	SLIGHT	MODERATE	SEVERE	NONE	SLIGHT	MODERATE	SEVERE	NONE	SLIGHT	MODERATE	SEVERE	NONE	SLIGHT	MODERATE	SEVERE	
ALUMINUM	●						○ ●				○ ●				○		●			○	●		NORFOLK SPECIMENS NAILED WITH GALVANIZED, CADMIUM
BARE STEEL	●							○	●			○ ●			○		●			○	●		PLATED AND COPPER NAILS RUSTED ON UNDERSURFACES
RESIN STEEL	●							○	●			○ ●			○		●			○	●		MUCH LESS CORROSION AND NO RUSTING ON UNDER-
GALVANIZED	●						○ ●				○ ●				○		●				○	●	SURFACES OF NBS SPECIMENS. SURFACE OF NORFOLK
COPPER	●							○		●		○ ●				○	●				○	●	SPECIMENS SHOWS SCATTERED PIN POINT CORROSION
CADMIUM PLATED	●						○ ●				○ ●					○	●				○	●	CORROSION PRODUCTS ARE BROWNISH-RED IN COLOR.
																							NO CORROSION ON SURFACES OF NBS SPECIMENS.

GALVANIZED STEEL SHEET - NAIL - WASHER INSPECTION AFTER 24 MONTHS EXPOSURE

NAIL	CONDITION OF SHEET						GALVANIC CORROSION				CORROSION AROUND NEOPRENE WASHER				CORROSION BENEATH LEAD WASHER				UNDERSURFACE CORROSION				REMARKS
	SPANGLES			RUSTED																			
	CLEAR	FAINT	INVISIBLE	SLIGHT	MOD	SEVERE	NONE	SLIGHT	MOD	SEVERE	NONE	SLIGHT	MODERATE	SEVERE	NONE	SLIGHT	MODERATE	SEVERE	NONE	SLIGHT	MODERATE	SEVERE	
ALUMINUM	○ ●						○ ●				○ ●					○ ●				○ ●			VERY SLIGHT INCREASE IN GENERAL SURFACE CORROSION
BARE STEEL	○ ●							○ ●			○ ●					○ ●				○ ●			PRINCIPAL DIFFERENCE BETWEEN THESE AND 12 MONTH
RESIN STEEL	○ ●							○ ●			○ ●					○ ●				○ ●			SPECIMENS. COATINGS WELL INTACT EVEN WHERE
GALVANIZED	○ ●						○ ●				○ ●					○ ●				○ ●			CONTACTED BY DISSIMILAR METAL NAILS AND WASHERS.
COPPER	○ ●							○ ●				○ ●				○ ●				○ ●			VERY LITTLE UNDERSURFACE CORROSION ON SPECIMENS
CADMIUM PLATED	○ ●						○ ●				○ ●					○ ●				○ ●			AT EITHER SITE.

ZINC ALLOY SHEET - NAIL - WASHER INSPECTION AFTER 24 MONTHS EXPOSURE

NAIL AND MATERIAL	CONDITION OF SHEET						GALVANIC CORROSION				CORROSION AROUND NEOPRENE WASHER				CORROSION BENEATH LEAD WASHER				UNDERSURFACE CORROSION				REMARKS
	LUSTER			CORRODED																			
	SHINING	GLIMMERING	DULL	SLIGHT	MOD	SEVERE	NONE	SLIGHT	MOD	SEVERE	NONE	SLIGHT	MODERATE	SEVERE	NONE	SLIGHT	MODERATE	SEVERE	NONE	SLIGHT	MODERATE	SEVERE	
GALVANIZED STEEL SHEET																							SPANGLES CLEARLY VISIBLE THROUGH
BARE STEEL				●				○ ●			○ ●					○ ●				○ ●			FAINT CORROSION PRODUCT ON GALVANIZ-
GALVANIZED				●			○ ●				○ ●					○ ●				○ ●			ED STEEL SPECIMENS EXPOSED AT NORFOLK
MATERIAL 1Z																							NO CORROSION PRODUCT ON SPECIMENS
BARE STEEL			○ ●	○ ●				○ ●				○ ●				○ ●				○ ●			AT NBS. CORROSION FROM CONTACT WITH
GALVANIZED			○ ●	○ ●			○ ●					○ ●				○ ●				○ ●			BARE STEEL NAILS AND LEAD WASHERS
MATERIAL 2Z																							ON ZINC ALLOY SHEETS NOT APPRECIABLY
BARE STEEL			○ ●	○ ●				○ ●				○ ●				○ ●				○ ●			DIFFERENT THAN AT THE END OF THREE
GALVANIZED			○ ●	○ ●			○ ●					○ ●				○ ●				○ ●			MONTHS EXPOSURE. CORROSION ON ZINC
MATERIAL 3Z																							ALLOYS IS FAIRLY UNIFORM WITH SOME
BARE STEEL			○ ●	○ ●				○ ●				○ ●				○ ●				○ ●			ISOLATED PITS AS DEEP AS 0.0015" ON
GALVANIZED			○ ●	○ ●			○ ●					○ ●				○ ●				○ ●			MATERIALS 3Z AND 5Z AND 0.001" ON
MATERIAL 4Z																							MATERIALS 1Z, 2Z, 4Z AND 6Z. MATERIAL 4Z
BARE STEEL			○ ●	○ ●				○ ●				○ ●				○ ●				○ ●			MOST EXTENSIVELY CORRODED ALTHOUGH
GALVANIZED			○ ●	○ ●			○ ●					○ ●				○ ●				○ ●			AMONG THOSE HAVING THE SHALLOWEST
MATERIAL 5Z																							PITS. UNDERSURFACE CORROSION ON
BARE STEEL			○ ●	○ ●				○ ●				○ ●				○ ●				○ ●			THESE MATERIALS IS VERY MILD AND NOT
GALVANIZED			○ ●	○ ●			○ ●					○ ●				○ ●				○ ●			APPRECIABLY DIFFERENT THAN THAT ON
MATERIAL 6Z																							SPECIMENS EXPOSED FOR ONLY THREE
BARE STEEL			○ ●	○ ●				○ ●				○ ●				○ ●				○ ●			MONTHS.
GALVANIZED			○ ●	○ ●			○ ●					○ ●				○ ●				○ ●			

○ SPECIMENS EXPOSED AT NATIONAL BUREAU OF STANDARDS

● SPECIMENS EXPOSED AT HAMPTON ROADS, VA. (NORFOLK)

TABLE 6.

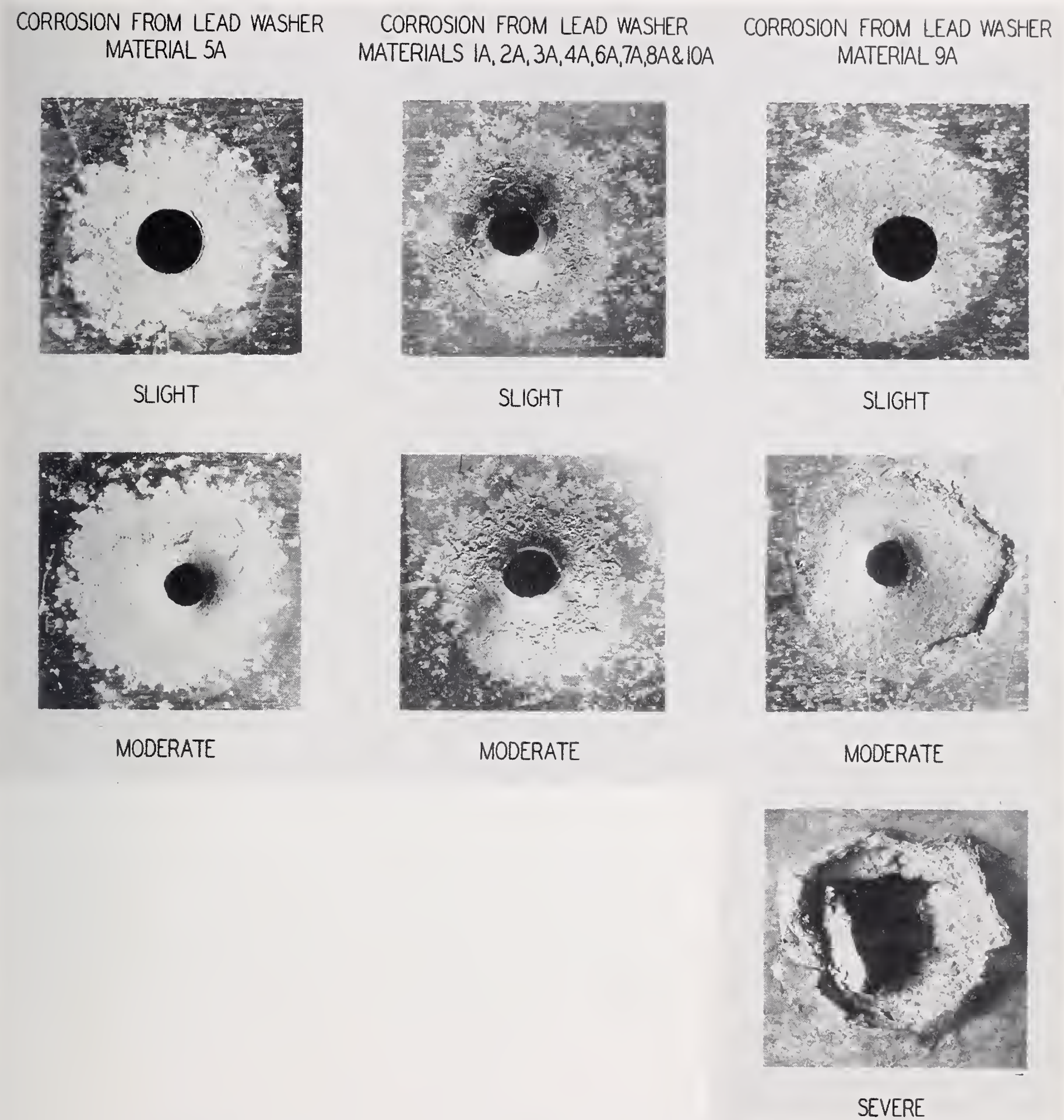

FIGURE 5. *Lead-washer corrosion ratings for aluminum-base alloys; $\times 2\frac{1}{2}$.*

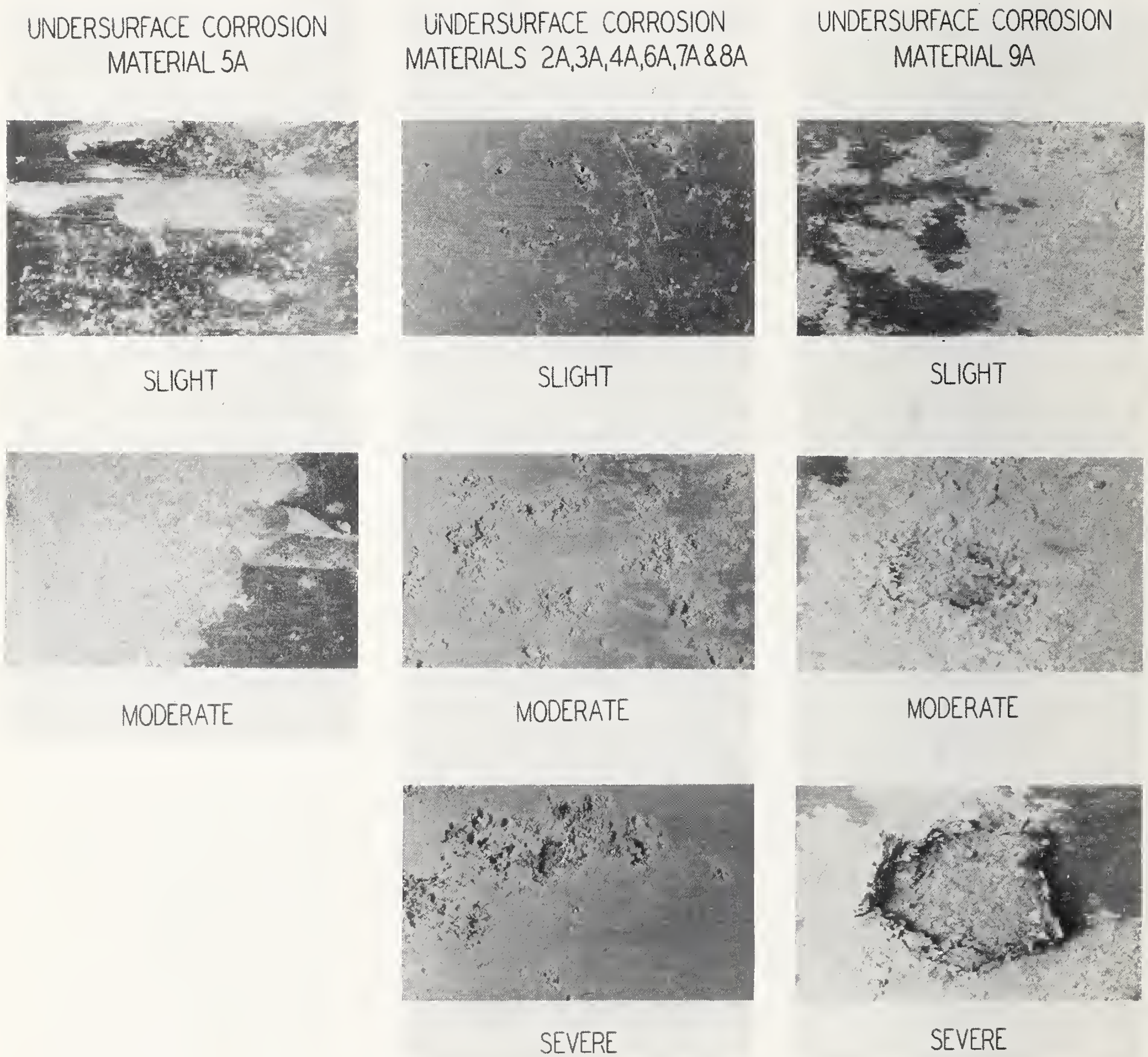

FIGURE 6. *Undersurface-corrosion ratings for aluminum-base alloys.*

Light-colored areas on photographs of materials 5A and 9A are areas where cladding has corroded away. ×2½.

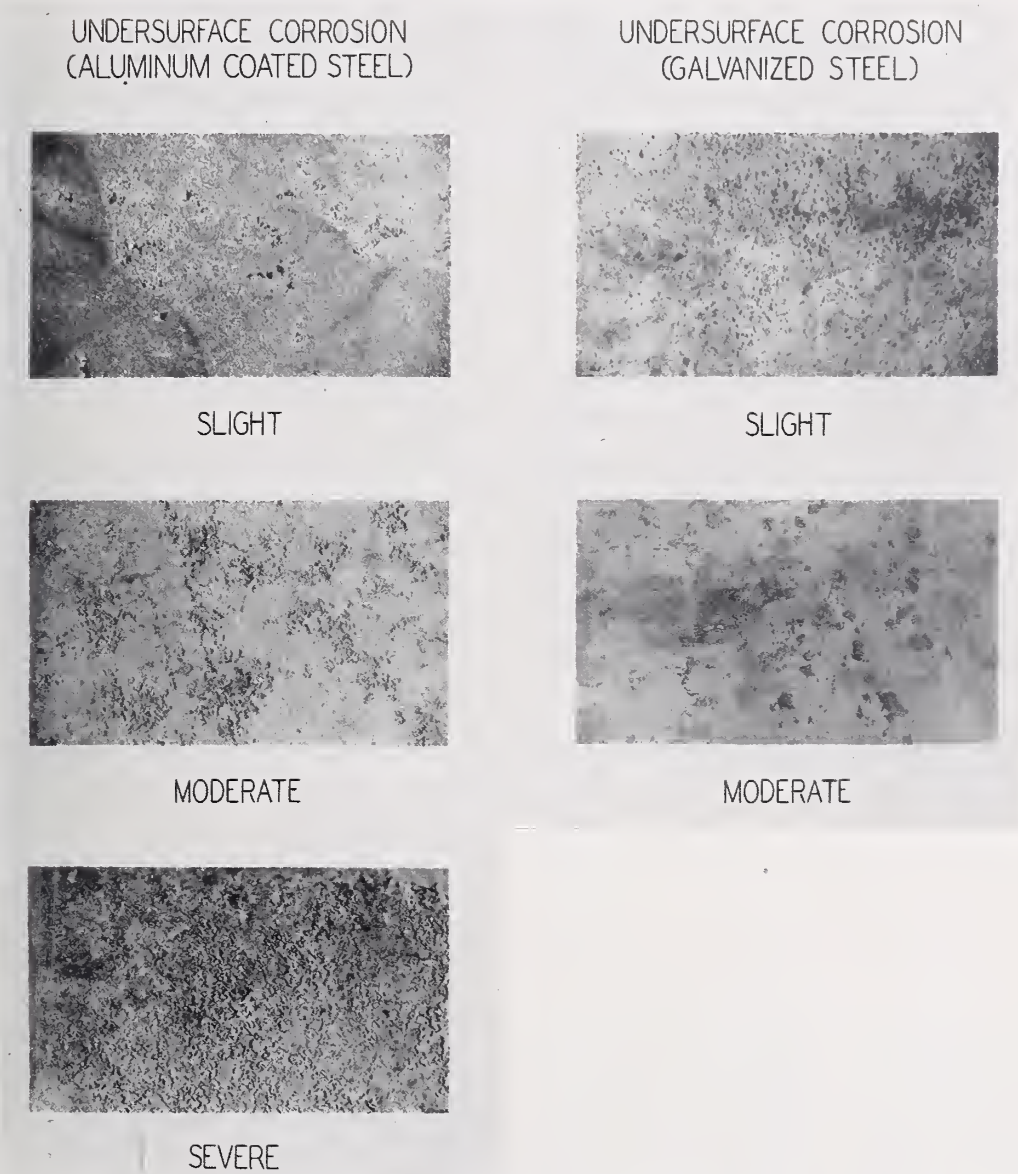

FIGURE 7. *Undersurface-corrosion ratings for aluminum-coated steel and galvanized steel sheets.*

Darkened areas are exposed steel in the case of the aluminum-coated steel and an underlaying zinc-iron alloy in the case of the galvanized steel. $\times 2\frac{1}{2}$.

The term "slight" as used in the inspection charts has a dual meaning, depending on whether it pertains to (1) corrosion from the atmosphere and not influenced by galvanic or contact effects, or (2) corrosion due to contacts with nails, washers, and wood. When referring to corrosion of type (1) "slight" is used to indicate the first traces of attack on the exposed surface, which in most instances was observable only with a microscope, and "moderate" is distinguishable from slight corrosion in that it refers to corrosive attack observable with the unaided eye. "Slight" corrosion, as used in the second case, generally indicates local attack, such as illustrated in figure 5 and usually visible to the unaided eye.

4. Results and Discussion

4.1. Aluminum Alloys

Reports of inspections made on the aluminum and aluminum-alloy building sheets after exposure of 6 and 24 months are given in tables 3 and 4, respectively. Data obtained in only 24 months of exposure are insufficient to establish an order of merit of the different materials with respect to their resistance to atmospheric corrosion, and, therefore, this objective of the investigation will have to be delayed until the results of the sets of specimens on more extended exposure warrant a comparison. At this time it is possible to make only the most general comments in regard to the aluminum and aluminum-alloy building materials as a group.

All the aluminum and the aluminum alloys investigated were unaffected, except for discoloration and fine spotting, by exposure to the atmosphere of Washington, D. C., for a period of 24 months. There was no conspicuous difference in the atmospheric corrosion resistance of any of these materials. Discoloration of the specimens was uniform over most of the surface of the specimens. Most of the spotting was concentrated in an area extending from the bottom edge of the specimens upward for a distance of approximately ½ in., the remaining surface being spotted to a lesser degree. Some materials were slightly more resistant to spotting than others.

At Norfolk the atmospheric attack on the surfaces of the aluminum alloys was only slightly greater than that on the Washington specimens. All unclad aluminum alloys exposed at Norfolk were noticeably spotted after 2 years of exposure, and microscopic examination of the spots showed them to be associated with superficial corrosion of the sheets. The clad aluminum-alloy sheets, 5A and 9A, corroded in spots completely through their cladding, and, as a consequence, the core materials had become exposed. However, there was no evidence of any attack on either of the core materials.

The 2-year-exposure tests indicate that when aluminum-alloy sheets are properly applied, they can be expected to give long satisfactory service in an atmosphere such as that in Washington, D. C. Similar exposure at Hampton Roads, Va. (Norfolk) foretells a relatively long satisfactory life for most of the materials, even though this type of atmosphere is known to be conducive to corrosion of aluminum alloys. Significant corrosion of the core of material 9A has been previously observed only after relatively large areas of the cladding had corroded away and, as in the present study, insufficient cladding has thus far been removed, it is not possible at this time to predict the life expectancy of this material in a coastal atmosphere. The presently available results suggest that all the unclad materials and the clad sheet 5A can be expected to render satisfactory service for considerable periods under coastal atmospheric conditions similar to those at the Norfolk exposure site.

The evaluation of the materials tested under improper installation procedures, has revealed, as expected, that they are subject to accelerated corrosion when in intimate contact with materials such as lead, steel and copper. The degree of acceleration varied for different materials and atmospheres.

Unclad sheets exposed at Washington were only mildly corroded at areas contacted by uncoated steel and copper nails and lead washers. No one material appeared to have superior corrosion resistance under these conditions. In the atmosphere of Norfolk, however, significant corrosion of the sheets occurred at areas of contact with uncoated steel and copper nails, the degree of intensity of such corrosion varying from "slight" after exposure for 3 months to "moderate" after exposure for 24 months. Corrosion due to contact with these nails on specimens exposed at Norfolk was definitely more prominent than that on specimens exposed in Washington. During the 24-month exposure period there were only two instances of perforation of the sheets, both occurring on material 3A at Norfolk after exposure for 6 months, one in the case of contact with a bare steel nail, the second where contacted by a lead washer. However, as no perforations were observed in the interval between the sixth and twenty-fourth month of exposure, the presence of these perforations may be considered as not characteristic of the behavior of this material. It is possible that these perforations were not caused solely by galvanic corrosion but were the result of a combination of pitting by galvanic action on the topside of the sheet due to the particular nail and washer, and corrosion on the undersurface of the sheet due to contact with the wood. As will be seen later on, this material was the least resistant of all the unclad materials to corrosion

when in contact with basswood in the atmosphere at Norfolk.

Although there was little difference in the intensity of corrosion on the different unclad materials caused by contact with dissimilar metal nails and washers, initial corrosion occurred on some materials earlier than it did on others. All specimens exposed at Norfolk had an incrustation of greyish-white corrosion products, similar to that

FIGURE 8. *Incrustation of corrosion products between lead washer and aluminum-alloy sheet.*

shown in figure 8, between the sheet and the lead washers after only 3 months of exposure. In the case of materials 1A and 10A this layer of corrosion products was very thin at the end of 3, 6, and 12 months of exposure and considerably heavier after 24 months, at which time moderate pitting occurred in these materials beneath the corrosion products. Moderate pitting similarly was observed on most of the other unclad materials after only 12 months of exposure. The moderate pitting that occurred on all the unclad materials, except 1A and 10A, after only 12 months may be accounted for by the fact that 1A and 10A were nailed to yellow pine, whereas the other materials were nailed to basswood, which appears to accelerate corrosion. It is possible that the earlier accelerated lead-washer corrosion of materials nailed to basswood was enhanced by corrosive fluids from the wood being drawn up by capillary attraction to the interface between the aluminum sheet and the lead washer. This condition did not exist where materials were nailed to yellow pine, which had no significantly corrosive effect on the aluminum alloys. It must be emphasized, however, that the accelerated corrosion at the contact with lead washers occurred only on sheets exposed in the coastal atmosphere and that no such accelerated corrosion of sheets nailed to basswood was observed on Washington exposed specimens. This suggests that any action of the fluids in the basswood in accelerating the corrosion of the sheets in contact with lead washers was associated with the coastal atmosphere.

The clad materials, 5A and 9A, exhibited radically different corrosion characteristics under conditions of improper installation. Material 5A was at least equal in corrosion resistance to all the unclad materials insofar as corrosion from contacts with bare steel and copper nails and lead washers was concerned. On the other hand, material 9A was badly corroded from contacts with these nails and with most lead washers exposed at Norfolk, potentially serious corrosion of the specimens being noted after only 6 months of exposure. The cladding on material 5A retarded pitting of the core material by lead washers until some time between 12 and 24 months of exposure, the first pitting of this material due to such contacts being noticed after 24 months of exposure. All unclad materials exposed at Norfolk were observed to have pitted due to contact with lead washers after only 3 to 6 months, the majority of materials being pitted after only 3 months.

Figure 9 illustrates the superiority of material 5A over 9A and the unclad sheets as regards re-

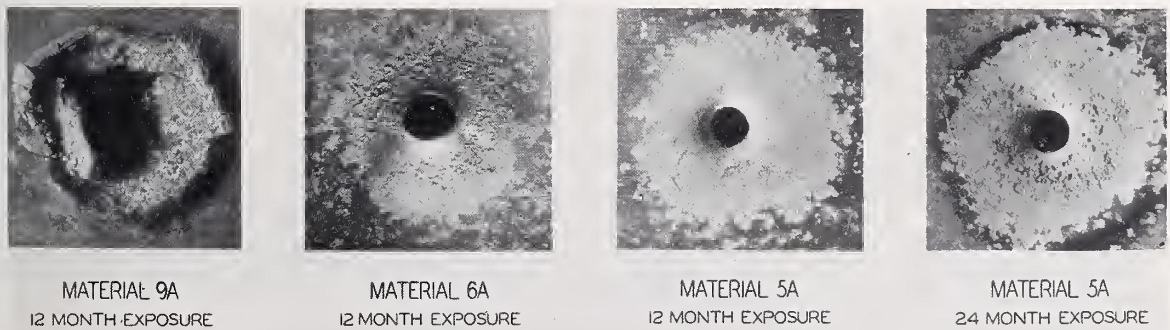

FIGURE 9. *Corrosive effect of lead washers in contact with clad and bare aluminum-alloy sheets in a marine atmosphere.*

Material 6A is a bare sheet; other sheets are clad.

sistance to a pitting type of corrosion. The resistance of material 5A to pitting is due solely to the sacrificial action of its cladding, so that after the cladding was corroded away to such an extent that it no longer could protect the core material by this electrolytic action, the core material pitted. This depletion of the cladding occurred between the twelfth and twenty-fourth months. The severe corrosion on material 9A is due to the low corrosion resistance of the core material, its cladding being capable of preventing corrosion of the core material only when relatively small areas of core material were exposed. Once a large area of cladding had corroded away, as in this case over the area where contacted by the lead washer, the core material corrodes severely owing to the intimate contact with the lead washer.

Where lead washers were used in conjunction with material 9A at Norfolk, except with galvanized steel nails, the corrosion of the sheet due to such contacts was so severe after 12 months of exposure that the material was considered as having failed. Figure 10 illustrates the difference in corrosion of material 9A due to lead washers where aluminum-alloy and galvanized-steel nails were used. In the latter, only the cladding has corroded away, and there was no significant attack on the core material, probably due to the inhibiting action of the zinc corrosion products of the galvanized steel nail that seeps in between the lead washer and the sheet.

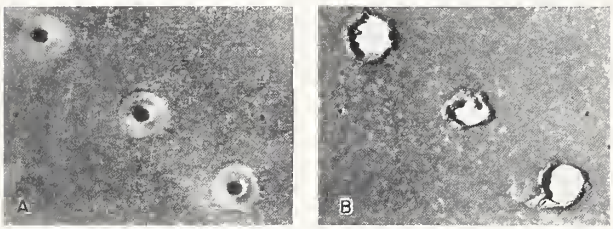

Figure 10. *Corrosive effect of lead washers on material 9A in a marine atmosphere.*

Sheet completely perforated where aluminum nail was used; only cladding corroded where galvanized nail was used. A, Lead washer-galvanized nail; B, lead washer-aluminum nail.

With respect to the corrosion on the surfaces of aluminum alloys contacting basswood, the results obtained thus far in the Washington, D. C., atmosphere indicate that this causes corrosion to a degree approaching that caused by contact between aluminum and nails of bare steel and copper. However, this corrosion can be prevented by proper insulation between the wood and metal sheet. Materials 1A and 10A, which were nailed to yellow pine, showed no corrosion after 12 months of exposure and only the faintest corrosion on the undersurface after 24 months. However, material 2A, similar to 1A, although made by a different producer, was significantly corroded on the undersurface after only 6 months at both exposure sites when nailed to basswood. Material 9A, which showed unusual corrosion on the undersurface after only 6 months of exposure when nailed to basswood, did not corrode on the undersurface after 6 months when nailed to yellow pine, as illustrated in figure 11. Further evidence that

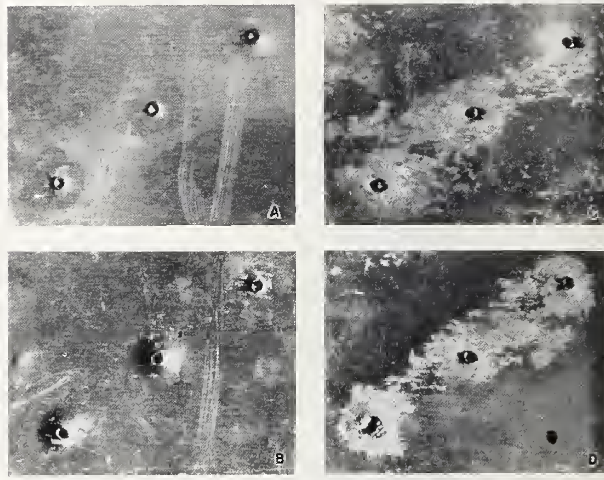

Figure 11. *Effect of 6-month contact of material 9A with basswood and yellow pine, respectively.*

Note abnormal corrosion of cladding (light areas) where contacted by basswood and absence of corrosion where contacted by yellow pine. A, Yellow pine, NBS site; B, yellow pine, Norfolk site; C, basswood, NBS site; D, basswood, Norfolk site.

basswood was the cause of the undersurface corrosion was observed in the cases of materials nailed with aluminum nails, except when lead washers were used. These sheets corroded even though, in the absence of lead washers, there was no possibility of dissimilar metal-corrosion products washing between the wood and the sheet.

The serious corrosion of the core material progressing from the undersurfaces of some of the 9A specimens is considered to be caused by both the contact with the basswood and the proximity of heavy metal nails and lead washers. The corrosion of the cladding on the undersurfaces of these specimens exposed at Norfolk was first observed after only 3 months. Those specimens nailed with steel and copper nails without washers, or with any type of nail, except galvanized nails, employing a lead washer, were considerably more corroded after 6 months of exposure than at the end of 3 months. It thus appears that some condition other than the contact with basswood was accelerating the corrosion on the undersurface. Serious corrosion was observed on the core material of only those sheets fastened with any nails (except galvanized) employing lead washers and with copper and steel nails without washers. From these observations it is postulated that iron and copper and/or lead deposited on the aluminum undersurface from solutions of corrosion products of the nails and washers seeping to this area set up

local couples with the aluminum, thus accelerating the corrosion of the aluminum. The initial corrosion of the cladding is attributed to contact with the basswood because 9A specimens similarly nailed to yellow pine showed no corrosion of the cladding after 6 months of exposure. It is of course recognized that the increased rate of corrosion attributed to basswood may be greater under the conditions of test reported in this paper than would be expected in a metal roof installation where less moisture usually is in contact with the uncovered portion of the wood.

The corrosive effect of the basswood was evident after only 3 months of exposure. At the end of this time most of the specimens in contact with this wood showed evidence of some corrosive attack. All materials, except 5A and 9A, exhibited a pitting type of attack. Materials 5A and 9A were attacked only on their claddings, with no attack on the core material. The cladding on material 5A had corroded away over comparatively large areas of the specimen. Subsequent inspections after 6, 12, and 24 months of exposure revealed that on most materials the pitting was at an increasing rate for the first 12 months and that it slowed down during the second 12-month period.

A significant characteristic of material 5A was revealed in this investigation, in that although considerable areas of cladding were corroded away after only 3 months of exposure, only the faintest evidence of pitting was detected after 24 months. This behavior of material 5A indicates its superiority over material 9A and the unclad materials for use under corrosive conditions that might be comparable to those of this test.

Material 3A was very susceptible to pitting due to contact with basswood in a coastal atmosphere, some specimens having perforated after only 6 months of exposure. After 24 months of exposure all specimens of this material were perforated. It is noteworthy that this material, only slightly more resistant to "undersurface corrosion" than material 9A when in contact with basswood in a coastal atmosphere, should be the most corrosion resistant of all materials in this respect in the atmosphere of Washington, D. C. A similar alloy, 4A, furnished by a different producer, corroded considerably on the undersurface when exposed at Washington but was much more resistant to this attack than material 3A when exposed at Norfolk.

The undersurface corrosion resistance of materials 2A, 6A, 7A, and 8A was intermediate to that of materials which showed the most and the least resistance to this type of attack. Material 7A exposed at Norfolk showed early indications of potentially serious corrosion on its undersurface, being approximately as corroded as material 3A after 6 months of exposure. Unlike 3A, however, its rate of corrosion decreased progressively between the sixth and twenty-fourth months.

After 12 months of exposure all specimens fastened with galvanized steel nails were noticeably less corroded on their undersurfaces than were specimens fastened with the other types of nails. After 24 months of exposure several of the specimens secured with galvanized nails were pitted to the same degree as those fastened with the other types of nails. However, the over-all beneficial effect of the galvanized nails in retarding a pitting type of corrosion was still apparent, because in most cases the aluminum materials thus nailed were the least corroded after 24 months of exposure.

The retardation of undersurface corrosion on sheets fastened with galvanized steel nails is believed to be caused by the washing of zinc corrosion products from the nail into the interface between the sheet and the wood. The increased corrosion between the twelfth and twenty-fourth months on some sheets so fastened was caused by an insufficiency of zinc corrosion products reaching the interface between the metal sheet and wood to retard corrosion of the aluminum.

Bare steel, resin-coated steel, or copper nails should never be used in conjunction with aluminum. Accelerated corrosion of aluminum alloys due to contact with these nails has been demonstrated in this investigation, particularly in the case of material 9A. The object in using resin-coated steel nails was to determine what effect, if any, the resin coating would have in breaking direct contact of the nail with the aluminum. It was apparent after the 3-month inspection period that no beneficial effect whatsoever was to be had from the resin coating, as the sheets fastened with this type of nail were as readily corroded because of contact with the nail as were sheets fastened with bare steel nails.

Although an aluminum-alloy nail is the proper one to use with aluminum-alloy building sheet, cadmium-plated and galvanized steel nails generally are considered acceptable substitutes for aluminum nails, inasmuch as no corrosion of the aluminum will occur so long as the coating on these nails remains intact. Once the steel of the nails is exposed, however, the aluminum will corrode galvanically because of contact with the exposed steel of the nail. Cadmium has a solution potential similar to that of these aluminum alloys and, therefore, there is very little or no galvanic corrosion of either material when cadmium and aluminum are in intimate contact with each other. Zinc will corrode only slightly when in contact with aluminum because, while zinc has a more electronegative potential than aluminum, the difference in potential is small.

The 24-month exposure tests of the galvanized nails in intimate contact with aluminum-alloy building sheets indicated that they had lost none of their effectiveness, although the outer zinc layer

on the nail heads not adjacent to the aluminum sheet had partially corroded away and exposed an intermediate zinc-iron alloy layer. The remoteness of this corroded area of the nail head from the sheet indicated that the depletion of the outer zinc layer was due to general atmospheric corrosion and not to galvanic effects. After exposure, the galvanized nails driven through the aluminum sheets were no different in appearance from those nails driven through holes drilled in the sheets nor was there any apparent difference in the appearance of the aluminum sheets fastened by the two methods.

The cadmium-plated steel nails darkened at both sites after only 3 months of exposure, and those used in conjunction with lead washers at Norfolk were covered with a fine whitish corrosion product during this initial period. This corrosion product was not observed on nails used with lead washers at Washington until after 6 months of exposure. During the interval between the time of the initial development of this corrosion product and the 24-month inspection period, this corrosion product had increased in volume and had taken on a yellowish tinge, indicating that perforation of the plating had occurred, with consequent rusting of the exposed steel of the nail. Only very faint white corrosion products were observed on nails used without washers and with neoprene washers after 24 months of exposure at both sites. Figure 12 illustrates the difference in appearance between

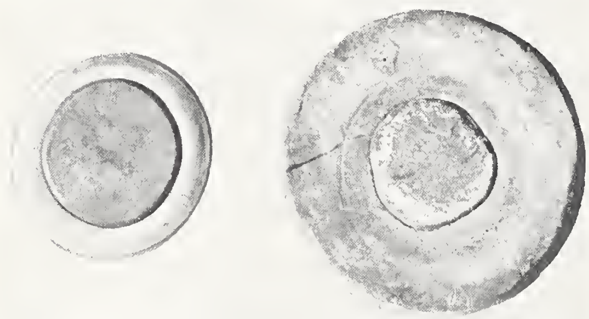

FIGURE 12. *Appearance of cadmium-plated steel nails after use with neoprene and lead sealing washers, respectively.*

Note white corrosion products on nail used with lead washer on right.

the cadmium plate on nails used with lead and neoprene washers after exposure for 6 months. Although the cadmium plate on nails used without washers or with neoprene washers was not noticeably perforated after 24 months of exposure, as indicated by the absence of the yellowish discoloration in their corrosion products, there was evidence of a trend toward deterioration of the plating similar to the initial deterioration of the plating observed on the nails used with the lead washers.

On the basis of the presently available results of this investigation, it would be difficult to accurately estimate the life expectancy of galvanized or cadmium-plated nails. However, the cadmium-plated nails tested, even without lead washers, probably would not serve satisfactorily for more than about 3 years. As commercially available cadmium-plated nails have considerably thinner coatings than those on the nails used in these tests, their life expectancy could be considerably less than those investigated. Nails used in these tests had cadmium coatings of from 0.0008 to 0.001 in. in thickness.

The grey molded neoprene washers used in this investigation were prone to harden and crack after prolonged exposure to sunlight. This hardening and cracking was first observed after only 3 months of exposure. Although the cracking of the washers was only slight after 3 months, it became progressively more prominent for longer exposure periods, evidence of considerable checking of this type of washer being observed after 24 months of exposure. There was no appreciable difference between the appearance of washers exposed in Washington and Norfolk. Despite the poor condition of the exposed surfaces of these washers, that part of the washer sealing the hole punched by the nail was free from cracks and apparently unaffected otherwise.

The sealing washers cut from neoprene sheet pigmented with carbon black showed no tendency to harden after exposure for 24 months. There was no evidence of cracking of this type of washer after exposure for 12 months. Figure 13 illus-

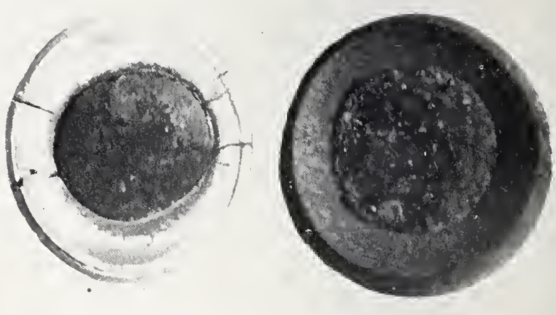

FIGURE 13. *Appearance of neoprene sealing washers after exposure for 1 year at Hampton Roads, Va.*

Note crack-free appearance of carbon-black-filled neoprene washer on right.

trates the difference in the grey molded neoprene washer and the washer cut from carbon-black-filled neoprene sheet after 12 months of exposure. Despite the superiority of the carbon-black-filled neoprene washers, insofar as resistance to hardening and cracking was concerned, they, too, had a tendency to crack at the areas adjacent to the sheet after exposure for 24 months. In this in-

vestigation two carbon-black-filled neoprene washers were used with each nail. The bottom washer, the one in intimate contact with the specimen, was the only one that had cracked (fig. 14). The top washer was free from any cracking (fig. 14).

A B

FIGURE 14. *Cracking of carbon-black-filled neoprene sealing washers after 2-year exposure to the atmosphere.*

A, Washer in normal position. Bottom washer cracked in highly stressed, exposed area. B, Washers in expanded position. Top washer free from cracks in highly stressed, unexposed areas.

Both washers were as pliable after 24 months of exposure as they were in their original condition. In the expanded view on the right of figure 14, the bottom washer is removed from its normal position to show the crack-free condition of the top washer. Examination of these washers showed this material to be subject to cracking on prolonged exposure to the atmosphere only if stressed in tension and then only when exposed to gases in the atmosphere and/or sunlight (areas adjacent to sheet, fig. 14). Thus the absence of cracks in the top washers shown in figure 14 may be explained by the fact that the bottom washers protected the highly stressed areas of the top washers from sunlight and from gases in the atmosphere. The soft, pliable condition of the cracked washer, however, suggests that gases in the atmosphere, rather than sunlight, were the cause of the cracking because sunlight would also have hardened the washers.

4.2. Aluminum-Coated Steel

The results of the 6- and 24-month exposure tests of the aluminum-coated steel specimens are given in tables 5 and 6. The aluminum-coated steel sheets showed good resistance to corrosion in the atmosphere of Washington, D. C., for 24 months. There was no indication of any attack of the aluminum coating.

At Norfolk very faint corrosion of the aluminum coating was noted at the end of 3 months of exposure. After 6 months widely scattered "pin-point" corrosion of the aluminum coating was observed. Faint specks of a reddish-brown corrosion product, indicative of perforation of the cladding and rusting of the underlying steel, were visible at the points where the aluminum coating had corroded. Very little progressive corrosion of the aluminum coating was observed after 24 months of exposure.

The aluminum-coated steel specimens behaved similarly to the aluminum-alloy specimens, insofar as corrosion from contact with copper and steel nails and lead washers was concerned. All contacts with these materials, except with lead washers on specimens exposed in Washington, caused perforation of the aluminum cladding in less than 24 months, the first perforations occurring on specimens exposed at Norfolk after only 3 months of exposure. Figure 15 is typical of the

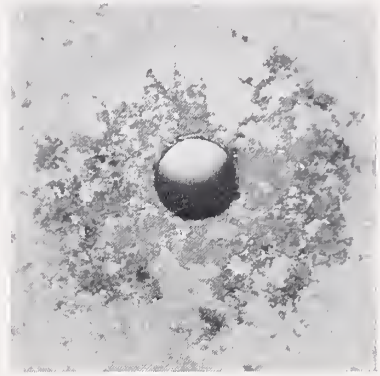

FIGURE 15. *Corrosion of aluminum-coated steel due to contact with lead sealing washer in a marine atmosphere.*

Dark area is exposed steel base.

corrosion of the aluminum coating caused by contact with a lead washer in a coastal atmosphere. The lead washers appeared to be equally or more harmful than bare steel and copper nails in accelerating the corrosion of the cladding in marine atmospheres.

Aluminum-coated steel sheets contacted by lead washers were only slightly corroded after 24 months of exposure in Washington, although isolated cases of slight corrosion were observed after 12 months of exposure. In this respect the aluminum-coated steel was similar to the aluminum alloys discussed above.

All aluminum-coated steel specimens were nailed to basswood boards. As in the case of the aluminum-alloy specimens so nailed, the contact with basswood caused serious corrosion on the undersurfaces of the aluminum-coated steel specimens, the first evidence of corrosion being observed after 3 months of exposure. The specimens exposed at Norfolk were significantly more corroded on their undersurfaces than were similarly nailed specimens exposed in Washington.

The most significant difference between the undersurface corrosion on the aluminum-alloy specimens and that on the aluminum-coated steel specimens occurred on those specimens fastened to basswood with galvanized steel nails. Contrary to the results obtained on aluminum alloys, aluminum-coated steel specimens so nailed and exposed at Norfolk were the most severely corroded, ex-

cept for those specimens fastened with copper nails. The aluminum-coated steel specimens fastened with galvanized nails exposed 24 months in Washington were as severely corroded as any specimens nailed with other types of nail, the aluminum coating of the undersurface having been completely removed and the exposed steel rusted. Specimens nailed with bare steel nails exhibited the least undersurface corrosion at both exposure sites. The corrosion on specimens fastened with aluminum nails was intermediate between that on the most and least severely corroded specimens. The portions of the steel base exposed in the severely corroded areas of the undersurfaces on the Washington specimens were found to be only superficially rusted after 24 months of exposure, whereas those on the Norfolk specimens were rusted to the point of scaling during the interval between the twelfth and twenty-fourth months.

The cut edges of the aluminum-coated steel sheets were only slightly rusted after 24 months of exposure, the rusting on the Norfolk specimens being slightly greater than that on the Washington specimens. This rusting was first noted after 3 months of exposure. There was evidence of slight galvanic corrosion of the aluminum coating immediately adjacent to the cut edges of the Norfolk specimens but not on specimens exposed at Washington.

The condition of the nails and washers used in conjunction with the aluminum-coated specimens was approximately the same as on the aluminum-alloy specimens.

4.3. Galvanized Steel

Reports of inspections made on the galvanized-steel specimens after exposures of 6 and 24 months are given in tables 5 and 6. All galvanized-steel specimens showed only slight attack of the zinc coating after 24 months of exposure at both Norfolk and Washington.

The first evidence of attack was widely scattered pin-point corrosion observed on the surfaces of the specimens after 3 months of exposure. This corrosion penetrated the outer zinc layer only and was discernible only under a microscope. This corrosion increased with time of exposure, resulting in a general darkening of the surface due to the elimination of the bright zinc outer layer and exposure of the darker intermediate layer of zinc-iron alloy. Although the specimens had darkened, the spangles were still clearly visible and the zinc coating was apparently attacked to a depth no deeper than that of the outer zinc layer of the coating. The specimens exposed at Norfolk showed slightly more attack than those at Washington.

After 3 months of exposure the Norfolk specimens were covered with a fine powdery greyish-white corrosion product that completely obscured the spangles. This corrosion product was less prominent on specimens withdrawn after 6, 12, and 24 months of exposure. Specimens exposed at the National Bureau of Standards had no observable corrosion products.

Although the corrosion on the surfaces was of the pin-point type, there was no penetration of the coating. This may be explained by the fact that, as the corrosion started at pin-point nucleii over the entire surface of the specimens, an intermediate zinc-iron alloy layer, cathodic to the zinc layer above it, was exposed beneath each of these pin-point pits. Pitting of this exposed underlying layer is prevented by the sacrificial action of the adjacent zinc until sufficient has been removed so that it no longer is effective in preventing pitting of the initially exposed area of the underlying layer. When this happens a pin-point pit will start in the exposed zinc-iron alloy intermediate layer.

There are several layers of zinc-iron alloys between the zinc outer layer and the steel base metal, each being progressively richer in iron than the layers above it. As any layer is cathodic to the ones above it, the underlying one will not pit until considerable of the anodic adjacent upper layer has corroded away. Therefore, gross areas of each upper layer of the coating on galvanized steel will be dissipated by corrosion before the adjacent underlying layer is attacked, with consequent little likelihood of deep-seated pitting.

The first indications of corrosion of the galvanized steel due to contacts with bare steel and copper nails and lead washers was observed after 3 months of exposure at both sites. The rate of corrosion due to these contacts was so slow, however, that even after 24 months of exposure this corrosion still was considered to be only slight.

All the nails, except galvanized, used in conjunction with these galvanized specimens have lower electronegative solution potentials than zinc, and, theoretically, they should cause corrosion of the galvanized coating on the galvanized steel when the nail and the sheet are in intimate contact. However, the solution potentials of zinc, aluminum, and cadmium are close together and nails of aluminum and cadmium-coated steel were observed to have little or no corrosive effect on the galvanized sheet. The solution potentials of bare steel, copper, and lead are considerably different from that of the zinc coating on the sheet, however, and these materials will accelerate corrosion of galvanized steel in intimate contact with them.

The lead washers caused some corrosion of the galvanized coatings, as shown in figure 16. This corrosion was first noticed after 3 months of exposure at both sites. The rate of corrosion of the coating was very slow, and after 24 months the

coating was only slightly more attacked than at the end of 3 months. There was no significant difference in intensity of corrosion on specimens exposed at Washington and Norfolk. Corrosion of the zinc coating due to contacts with bare steel and copper nails was about equal to that produced by contact with the lead washer, only the outer zinc layer of the coating being attacked.

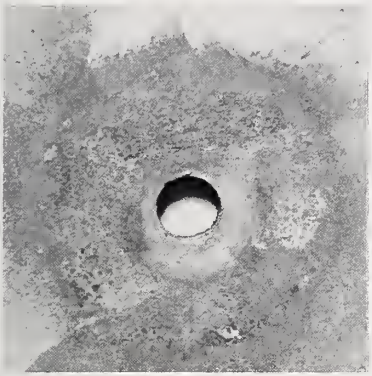

FIGURE 16. *Corrosion of galvanized steel due to contact with a lead sealing washer.*

Circular darkened area is exposed zinc-iron alloy layer.

All galvanized-steel specimens were nailed to yellow-pine boards. Except for the anomalous behavior of three specimens at the Norfolk site secured on the 3-month-exposure panel with cadmium-plated steel, galvanized steel, and copper nails, in which cases the undersurfaces of the specimens were badly corroded, the contact with wood had very little corrosive effect at either site on the undersurface of the galvanized specimens.

The cut edges of the galvanized-steel specimens had rusted superficially after 3 months of exposure at both sites and did not differ in this respect after 24 months.

The condition of the nails and washers used with the galvanized-steel specimens was similar to that of these accessories used with the aluminum-coated steel and aluminum-alloy specimens.

4.4. Zinc Alloys

Results of inspections made on the zinc-alloy specimens after exposures for 6 and 24 months are incorporated in tables 5 and 6.

All the zinc alloys investigated showed good resistance to corrosion in the atmospheres of Norfolk and Washington, D. C. for 24 months, and this behavior suggests that they should give satisfactory service in such atmospheres.

The galvanized-steel sheets exposed with the zinc-alloy specimens for comparison purposes were in good condition at both sites after 24 months of exposure. The behavior of these galvanized specimens, as regards corrosion of the coatings from the atmosphere and due to contact with bare steel nails, lead sealing washers, and wood, was not unlike that of the similarly nailed galvanized-steel specimens discussed above.

Galvanic corrosion of the zinc-alloy sheets due to contacts with bare steel nails and lead sealing washers was only mild, at most, and there was no appreciable difference in the degree of corrosion from these sources on specimens exposed at Norfolk and Washington, respectively. Also, no one alloy appeared to be significantly different than any other alloy, insofar as the effect of these nails and washers was concerned.

All the zinc alloys exhibited a pitting type of corrosion over their entire surfaces, and after 24 months of exposure the maximum depth of the pits varied from 0.0015 in. on materials 3Z and 5Z to 0.001 in. on 1Z, 2Z, 4Z, and 6Z. As the maximum-depth pits are approximately only twice as deep after 24 months of exposure (0.0015 in.) as after 3 months (approximately 0.0007 in.), it is obvious that the rate of pitting decreases with time. It is probable that this decreasing rate is due to the formation in the pits of zinc carbonates, oxides, or hydroxides, or combinations of these, which have some protective effects.

Although these materials have not been exposed sufficiently long to permit any conclusions as to their relative corrosive resistance, there are indications that they vary. Thus, after each exposure period, those materials containing the least copper, alloys 3Z and 5Z (actual analysis, in percent, showed copper as follows: 1Z, 0.89; 2Z, 1.03; 3Z, 0.46; 4Z, 0.96; 5Z ,0.45; and 6Z, 1.13), were found to have more and slightly deeper corrosion pits than those having the highest percentages of copper (alloys 1Z, 2Z, 4Z, and 6Z).

Materials 3Z and 5Z, which were in the cold-rolled condition, were slightly more corroded than hot-rolled materials 4Z and 6Z and also slightly less corrosion resistant than materials 1Z and 2Z, which also are cold-rolled. Since materials 1Z, 2Z, 4Z, and 6Z contained approximately twice as much copper as materials 3Z and 5Z, and since materials 1Z, 2Z, 3Z, and 5Z had been similarly rolled, it appears that the corrosion resistance of the zinc-alloy sheets is influenced more by their copper content than by their rolled condition.

The effect of magnesium content on the corrosion resistance of the zinc alloys is uncertain. However, materials of the same copper content and similarly containing the highest percentages of magnesium appear to be more uniformly corroded than those of the lowest magnesium content. This is illustrated in the enlarged photographs of the corroded surfaces of the six materials in figures 17 and 18. Material 2Z, which has a higher magnesium content (by actual analysis) than 1Z, is

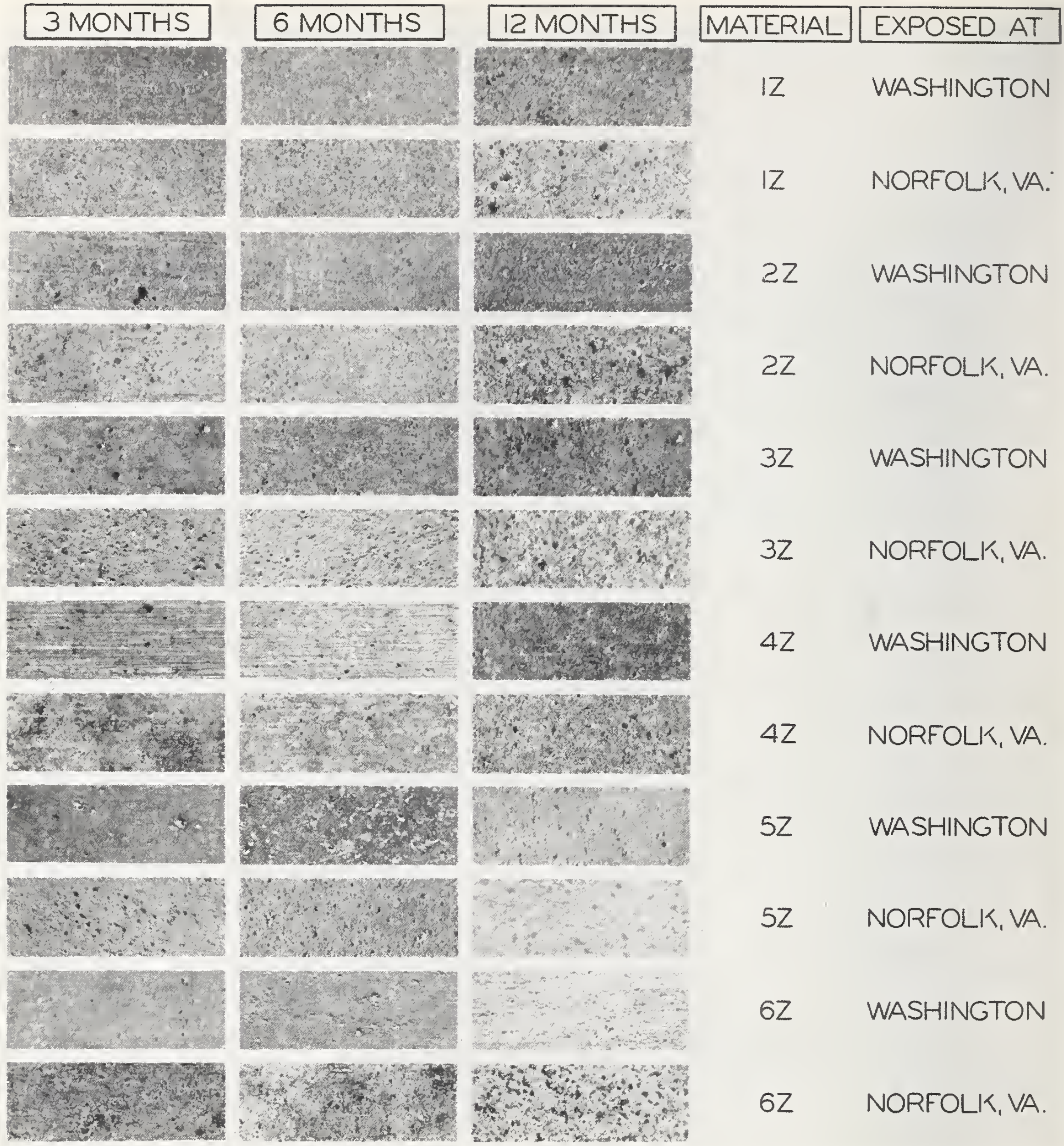

FIGURE 17. *Surface appearance of zinc alloys after exposure of 3, 6, and 12 months; × 17.6.*

more evenly corroded than the latter. Since these materials are both in the cold-rolled condition and contain approximately the same amount of copper, the results suggest that the higher magnesium content of material 2Z may be the contributing factor in promoting its more uniform corrosion. The same can be said of materials 3Z and 5Z, material 5Z having the higher magnesium content of these two cold-rolled materials, which have approximately the same copper content, and materials 4Z and 6Z, material 6Z containing the most magnesium of these two hot-rolled materials having approximately the same copper content.

Some corrosion of the zinc alloys occurred around the peripheries of neoprene washers used with galvanized steel nails despite the retention of continuous coatings on the nails. This corrosion is attributed to entrapped dirt or fine cinders at those points and not to any galvanic corrosion between the sheet and the nails, which will occur only when the steel of the nail becomes exposed because of corrosion of its galvanized coating.

FIGURE 18. *Surface appearance of zinc alloys after exposure for 24 months;* × *17.6.*

5. Conclusions

This investigation of sheet-metal materials was initiated to determine the relative corrosion resistances of materials commonly used in the building industry and to illustrate how improper installation practices can cause premature deterioration of materials which, when properly installed, can be expected to give long satisfactory service. The materials investigated were nailed to wood boards with a variety of nails and sealing washers that might be used in the building industry and were exposed to the atmosphere of Washington, D. C., and Norfolk, Va., for a period of 2 years.

Exposure for 2 years is too short a time in which to draw definite conclusions as to the relative merit of any of the materials investigated, but warrants some conclusions and recommendations regarding installation practices of sheet-metal building materials.

1. Lead in intimate contact with aluminum causes accelerated corrosion of the latter in a coastal atmosphere. It is recommended, therefore, that lead sealing washers not be used in conjunction with aluminum building sheets in such an atmosphere.. Because of insufficient data regarding the corrosive effect of lead in contact with aluminum in inland, nonindustrial atmospheres, such as that in Washington, D. C., definite recommendations cannot be made at this time regarding the advisability of using these washers under such atmospheric conditions.

2. Aluminum and aluminum alloys in intimate contact with certain kinds of wood may be seriously corroded on the contacting surfaces. Therefore, all wood surfaces to be covered with aluminum building sheets should first either be painted properly or covered with asphalt-impregnated felt or water-resistant building paper to preclude contact of the aluminum with the wood.

3. Aluminum nails only should be used in conjunction with aluminum building materials. Serious corrosion may be caused on aluminum sheet by securing them with nails of bare steel, resin-coated steel, or copper. Cadmium-plated steel nails also were found unsatisfactory for use in conjunction with aluminum building sheets. Although the galvanized steel nails were found intact after 2 years of exposure, they showed some evidence of approaching deterioration and, therefore, it is reasonable to conclude that when such nails are used for fastening aluminum building sheets, the sheets will not render the maximum expected life.

4. Sealing washers molded from neoprene pigmented with carbon black have longer life than similar washers without carbon black, and, although the former have been noted to crack after 2 years of exposure to the atmosphere, they do not become hard and brittle, as is the case of neoprene washers without carbon black. The cracking of either type of neoprene washer does not appear to impair their weather-proofing properties, as the cracks do not extend to those portions in intimate contact with the sheets in the immediate vicinity of the nail puncture.

5. The conclusions and recommendations regarding aluminum sheet with respect to the use of nails, washers, and insulation against wood also are applicable to the aluminum-coated steel sheets.

6. Galvanized sheet should be secured with aluminum-alloy or galvanized steel nails as these were the only types of those investigated that showed no evidence of being significantly corroded or causing galvanic attack on the sheet.

7. Neoprene was found to be more promising than lead for sealing washers that may contact galvanized sheet, as there was evidence of galvanic corrosion by lead washers but no deleterious effects by neoprene. Galvanized nails are more suitable for securing zinc-alloy sheet than bare steel nails as the latter cause accelerated corrosion of the sheet at the area of contact. Although no aluminum-alloy nails were used with the zinc-alloy sheets, the behavior of galvanized sheets where contacted by aluminum-alloy nails, suggests that this nail may be more satisfactory than galvanized nails for use with zinc-alloy sheets. This is based on the fact that zinc in contact with aluminum will corrode at a slower rate than will zinc in contact with steel, a condition which will prevail when the zinc coating on the galvanized nail corrodes away under normal atmospheric exposure.

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[Continued from cover page II]

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